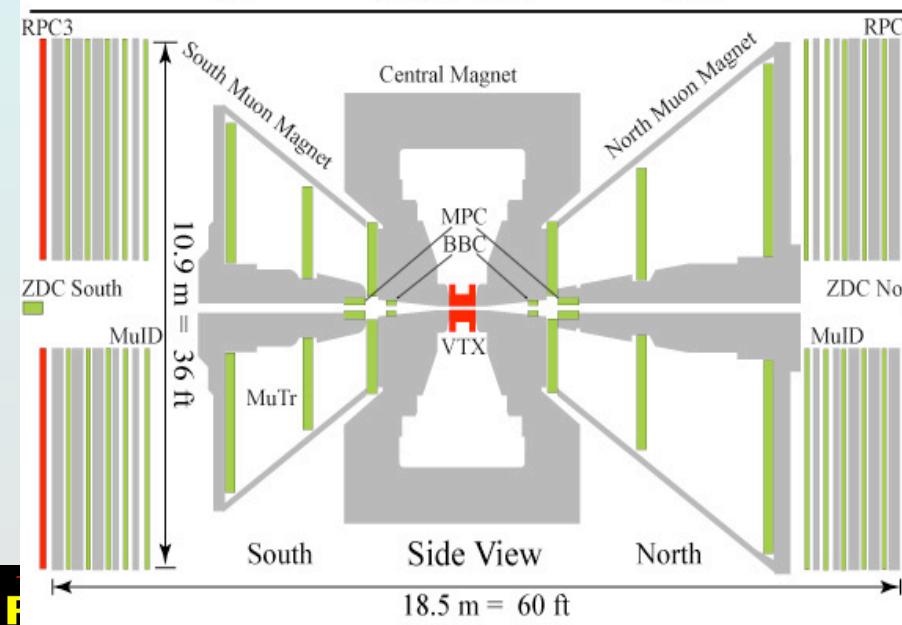
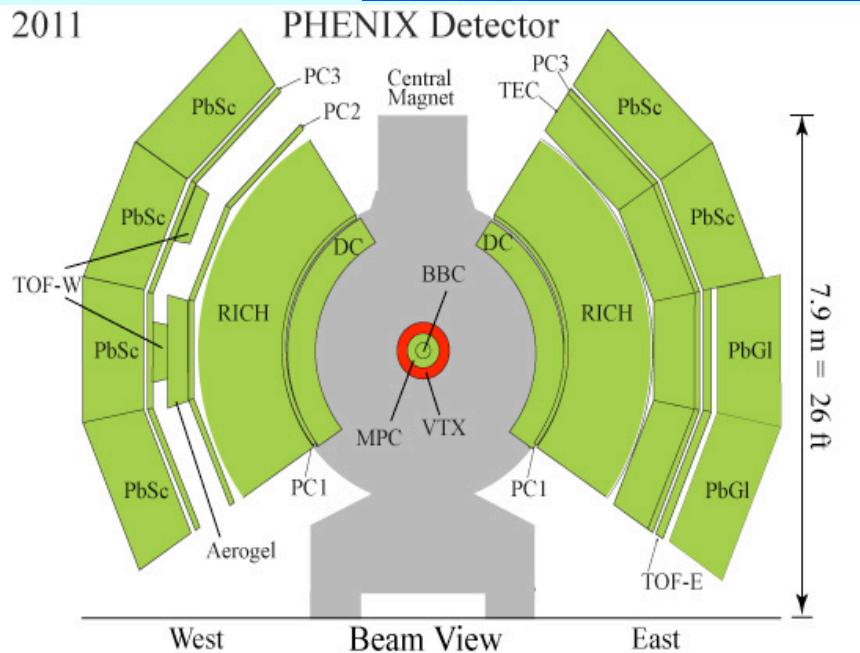


# The PHENIX Experiment at RHIC

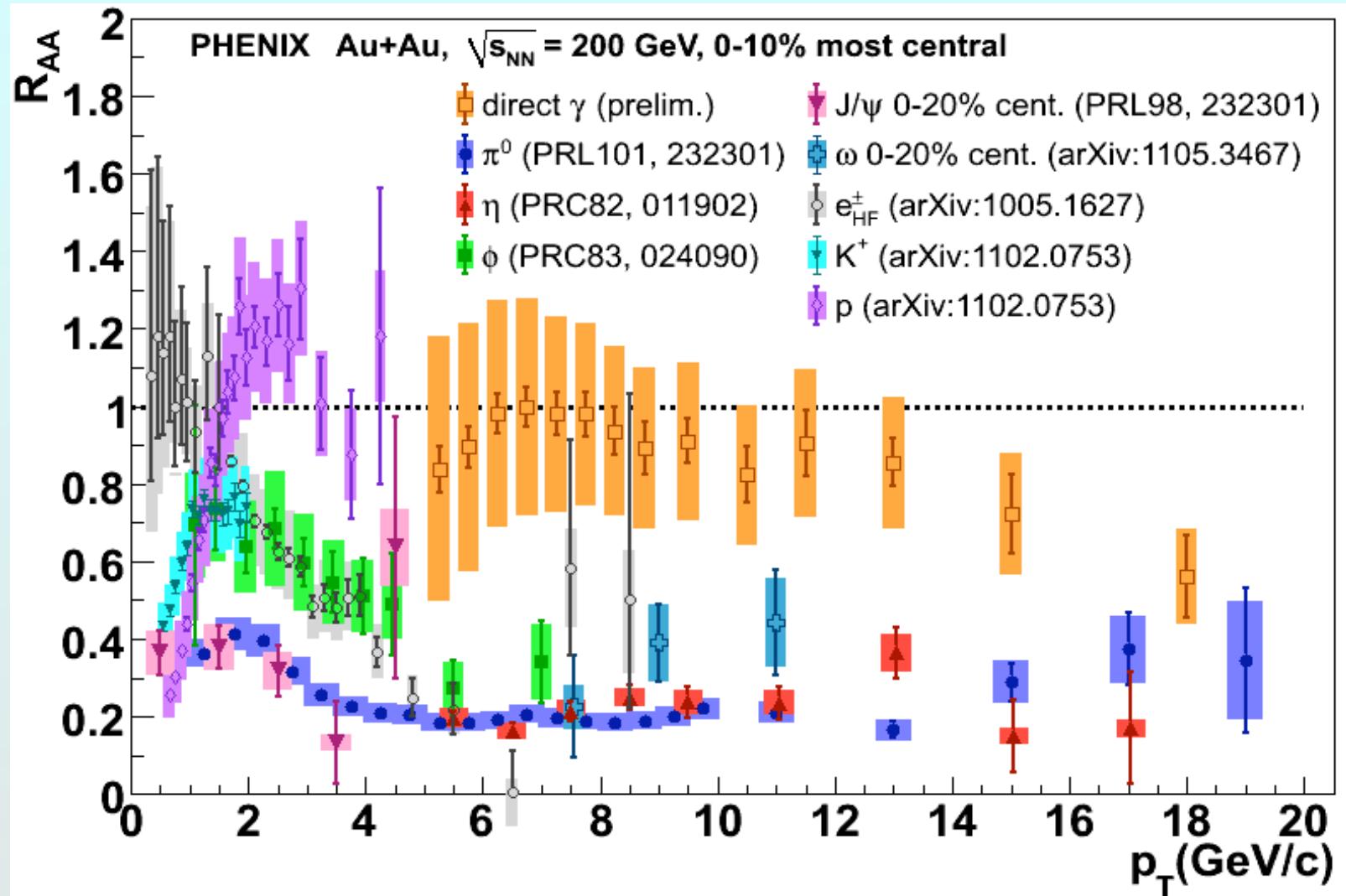


*Barbara Jacak for  
the PHENIX  
Collaboration*

## Outline

- Productivity
- Physics impact; new results
- Evolution of the PHENIX Detector
  - Physics with the HBD, VTX and Muon Trigger
  - Upgrades under construction and planned
  - Project management approach
- Data taking in the high rate environment
- Future planning
- Issues and Concerns

# PHENIX: unprecedented reach and precision



Superb particle ID, high rate capability and excellent trigger:  
broad physics capabilities over a large kinematic range



# Productivity

## New papers and preliminary results\*

- Pin down initial state using d+Au collisions
  - First new constraints on  $\eta/s$
  - Discovery of direct photon flow
  - Measure W cross section, first look at  $A_L$
  - J/ $\psi$  suppression at 62 GeV
- 
- *PHENIX has published 100 papers in refereed journals*
  - *submitted 16 papers in the past 12 months*
  - *published 13 + 1 in proof in the past 12 months*
  - *~35-40 preliminary analysis results*

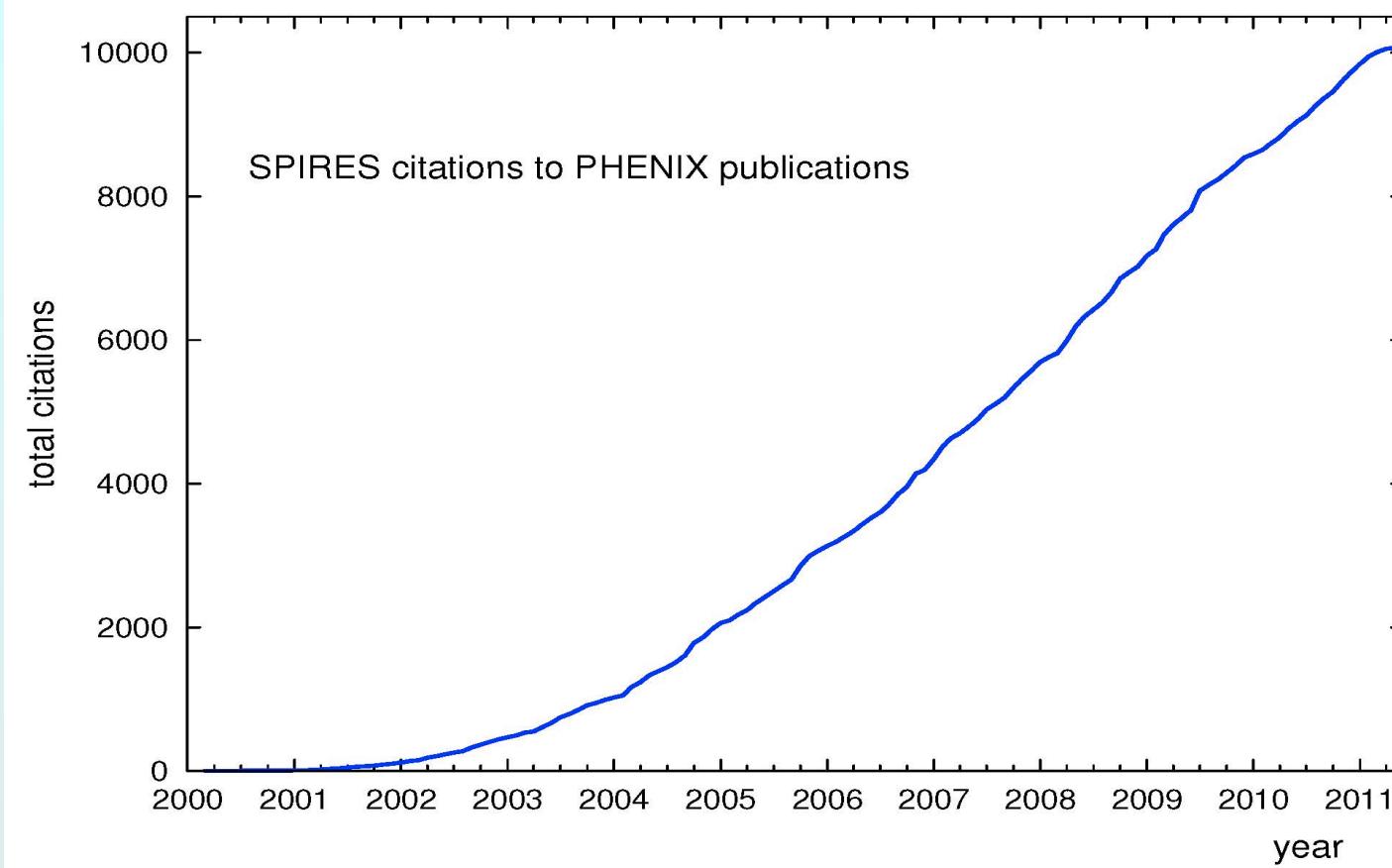
\* Some more details follow



## Other papers in the past year

- **J/ $\psi$ ,  $\psi'$ ,  $\chi_c$**  1105.1966
- **$\omega$  production in pp,dAu, CuCu, AuAu** 1105.3467
- **J/ $\psi$  suppression at high  $p_T$**  1103.6269
- **Identified hadron spectra in p+p** *PRC83, 064903 (2011)*
- **Away jet suppression vs. reaction plane** 1010.1521
- **J/ $\psi$  suppression in cold nuclear matter** 1010.1246
- **hadron cluster ALL** 1009.4921
- **electron-hadron correlations** *PRC83, 044912 (2011)*
- **meson  $m_T$  scaling in p+p** *PRD83, 052004 (2011)*
- **$\phi R_{AA}$**  *PRC83, 024909 (2011)*
- **$\eta \sigma$  and ALL** *PRD83, 032001 (2011)*
- **J/ $\psi A_N$**  *PRD82, 112008 (2010)*
- **$\gamma$ -h correlations in p+p** *PRD82, 012001 (2010)*
- **$\pi^0$  vs. reaction plane** *PRL105, 142301 (2010)*

## Over 10K citations of PHENIX papers

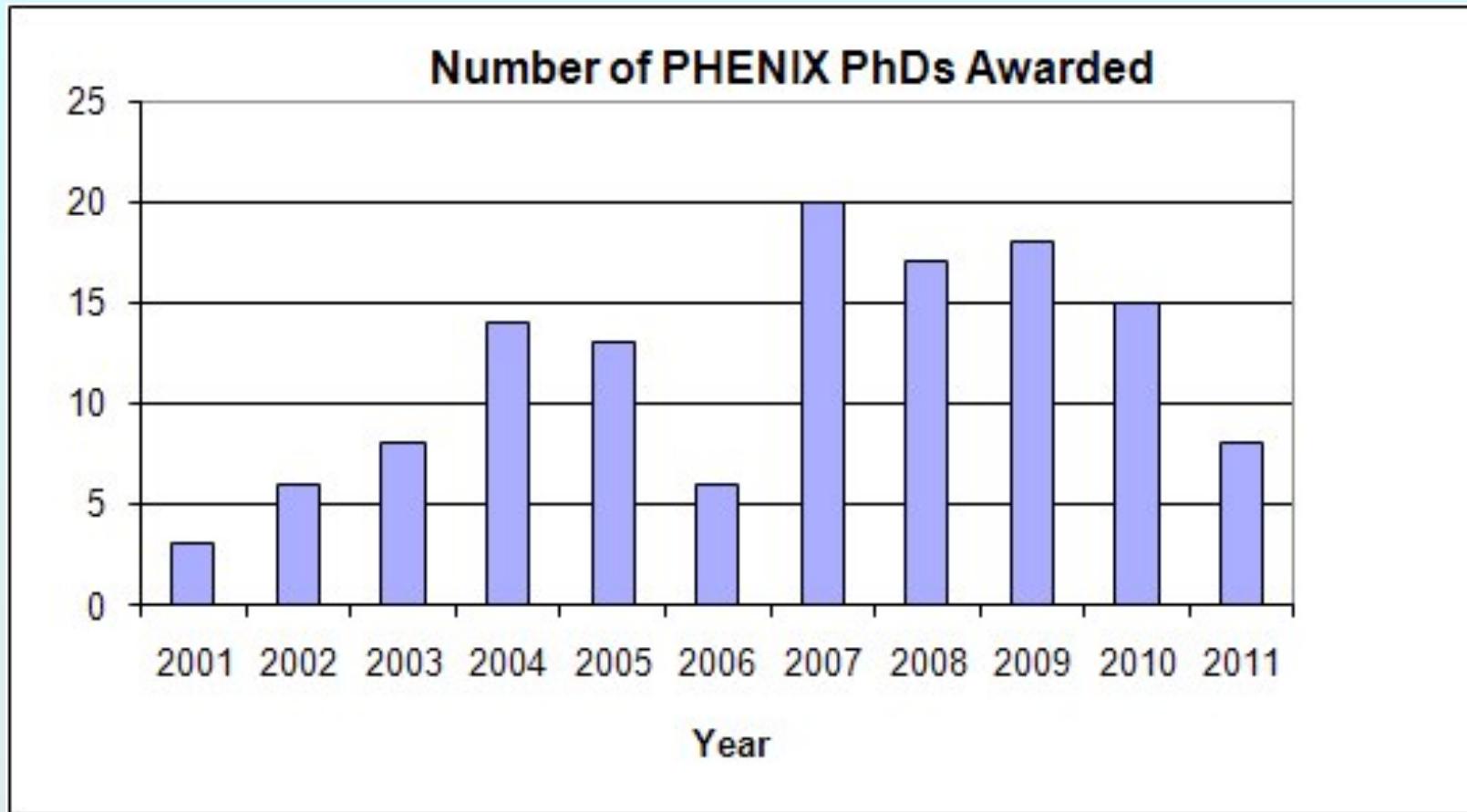


Citation *rate* remains high, as in past years

NB: PHENIX white paper has 1096 citations;  
jet quenching discovery paper has 593



## 121 PHENIX Ph.D.'s to date



> 6 of students are currently writing their theses and will defend this summer



## Recent Physics Accomplishments

# Context: QCD matter at T =300-600 MeV

- Collective flow with low viscosity/  
entropy ratio: "perfect liquid"

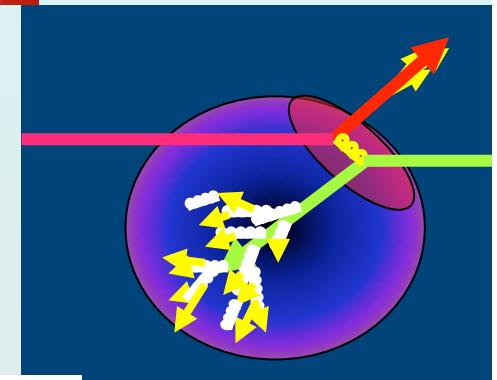
How low? Strong coupling...



Example of the viscosity of milk.  
Liquids with higher viscosities will not make such a splash when poured at the same velocity.

- Opacity very high  
Effectively stops quarks & gluons

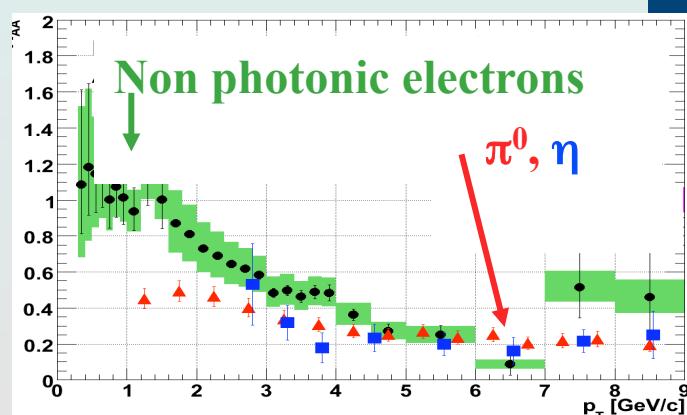
How and why? Strong coupling...



- Even heavy quarks lose energy & flow

Not expected from pQCD; mechanism?

->(very) strong coupling



- Color is screened  
How much?



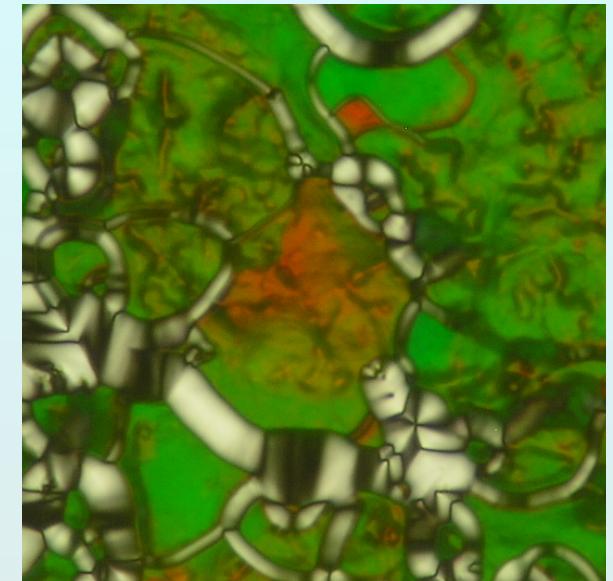
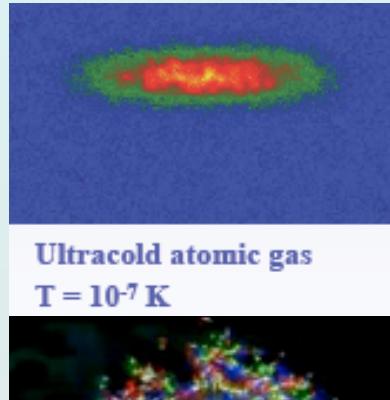
## Similar to forefront question in other fields!

*Quark gluon plasma is like other systems with STRONG COUPLING  
– all exhibit liquid properties & phase transitions*



Dusty plasmas &  
warm, dense plasmas  
have liquid and even  
crystalline phases

Cold atoms:  
coldest & hottest  
matter on earth  
are alike!



Strongly correlated  
condensed matter:

*In all these cases have a competition:*

*Attractive forces  $\Leftrightarrow$  repulsive force or kinetic energy*

*Result: many-body interactions; quasiparticles exist?*

# NSAC HI

## Milestones

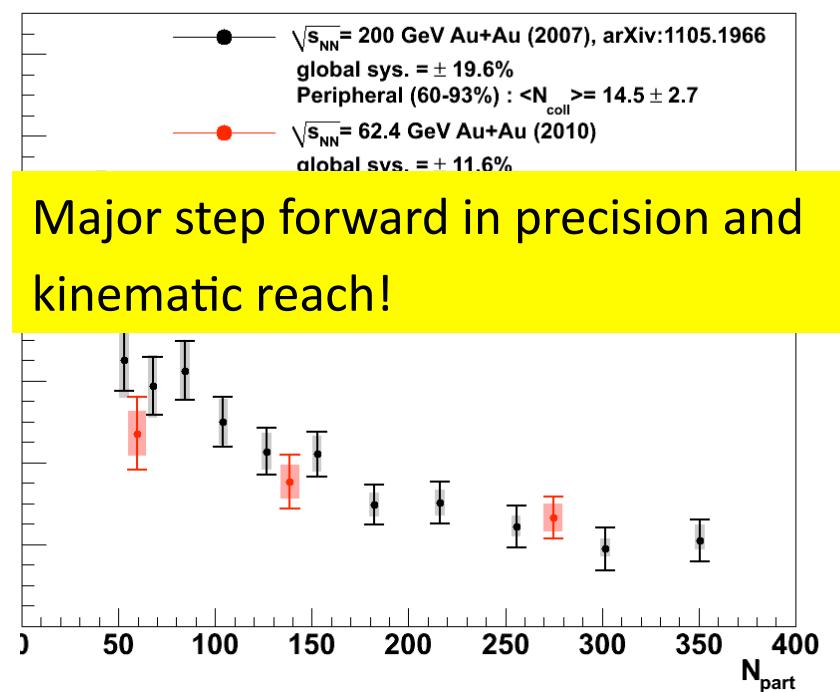
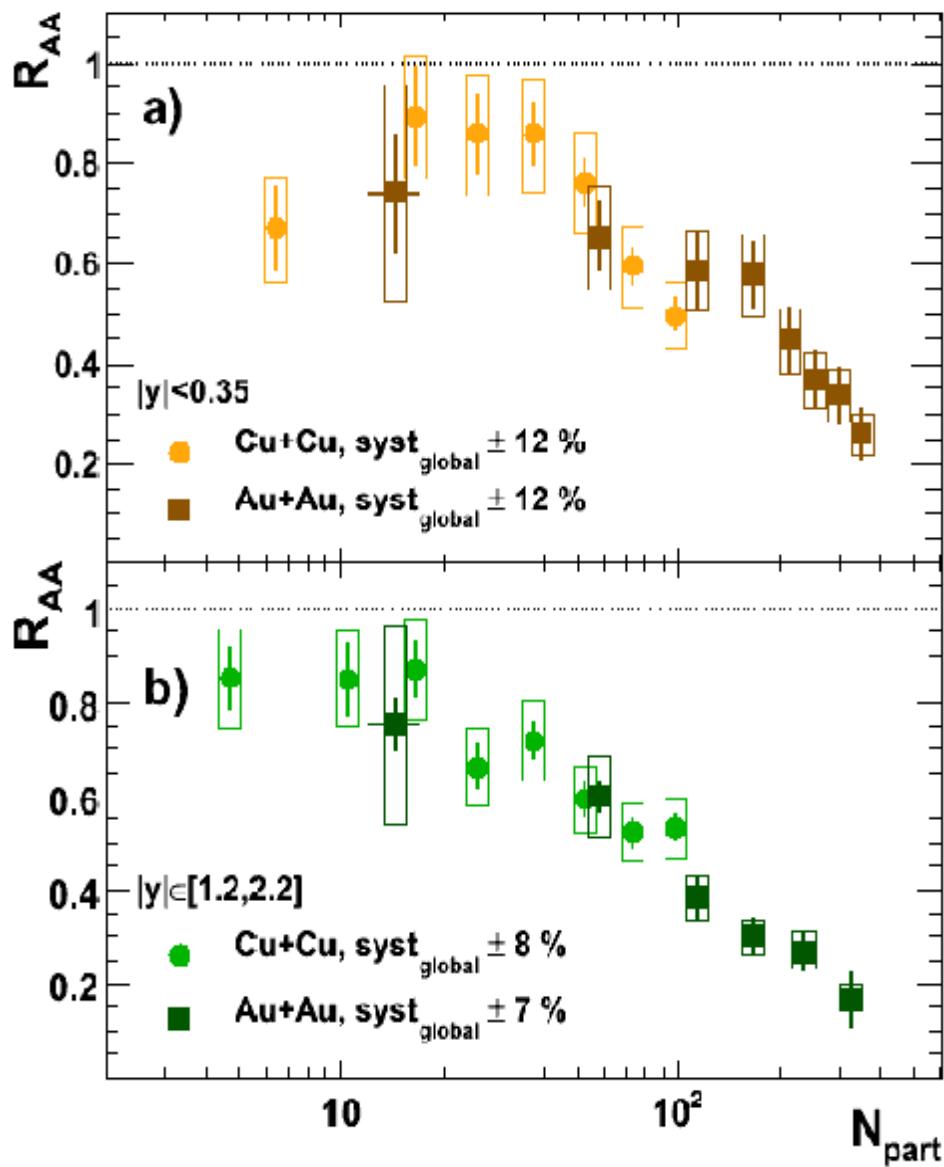


| Year | #             | Milestone   |
|------|---------------|---|
| 2009 | DM4           | Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC.   |
| 2010 | DM5           | Measure the energy and system size dependence of J/ $\Psi$ production over the range of ions and energies available at RHIC.  |
| 2010 | DM6           | Measure $e^+e^-$ production in the mass range $500 \leq m_{e^+e^-} \leq 1000$ MeV/c $^2$ in $\sqrt{s_{NN}} = 200$ GeV collisions.   |
| 2010 | DM7           | Complete realistic calculations of jet production in a high density medium for comparison with experiment.  |
| 2012 | DM8           | Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions.  |
| 2015 | DM9<br>(new)  | Measure bulk properties, particle spectra, correlations and fluctuations in Au + Au collisions at $\sqrt{s_{NN}}$ from 5 to 40 GeV to search for evidence of a critical point in the QCD matter phase diagram.  |
| 2014 | DM10<br>(new) | Perform calculations including viscous hydrodynamics to quantify, or place an upper limit on, the viscosity of the nearly perfect fluid discovered at RHIC.   |
| 2014 | DM11<br>(new) | Measure jet and photon production and their correlations in A $\approx$ 200 ion+ion collisions at energies from $\sqrt{s_{NN}} = 30$ GeV up to 5.5 TeV.   |
| 2016 | DM12<br>(new) | Measure production rates, high pT spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma. |
| 2018 | DM13<br>(new) | Measure real and virtual thermal photon production in p + p, d + Au and Au + Au collisions at energies up to $\sqrt{s_{NN}} = 200$ GeV.   |

# Spin Physics Milestones

| Year | #    | Milestone  |
|------|------|--|
| 2013 | HP8  | Measure flavor-identified q and anti-q contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.                          |
| 2013 | HP12 | Determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.               |
| 2015 | HP13 | Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering. |

# J/ $\psi$ vs. system size, $\sqrt{s}$



Major step forward in precision and kinematic reach!

○ obvious pattern of the suppression with energy density.

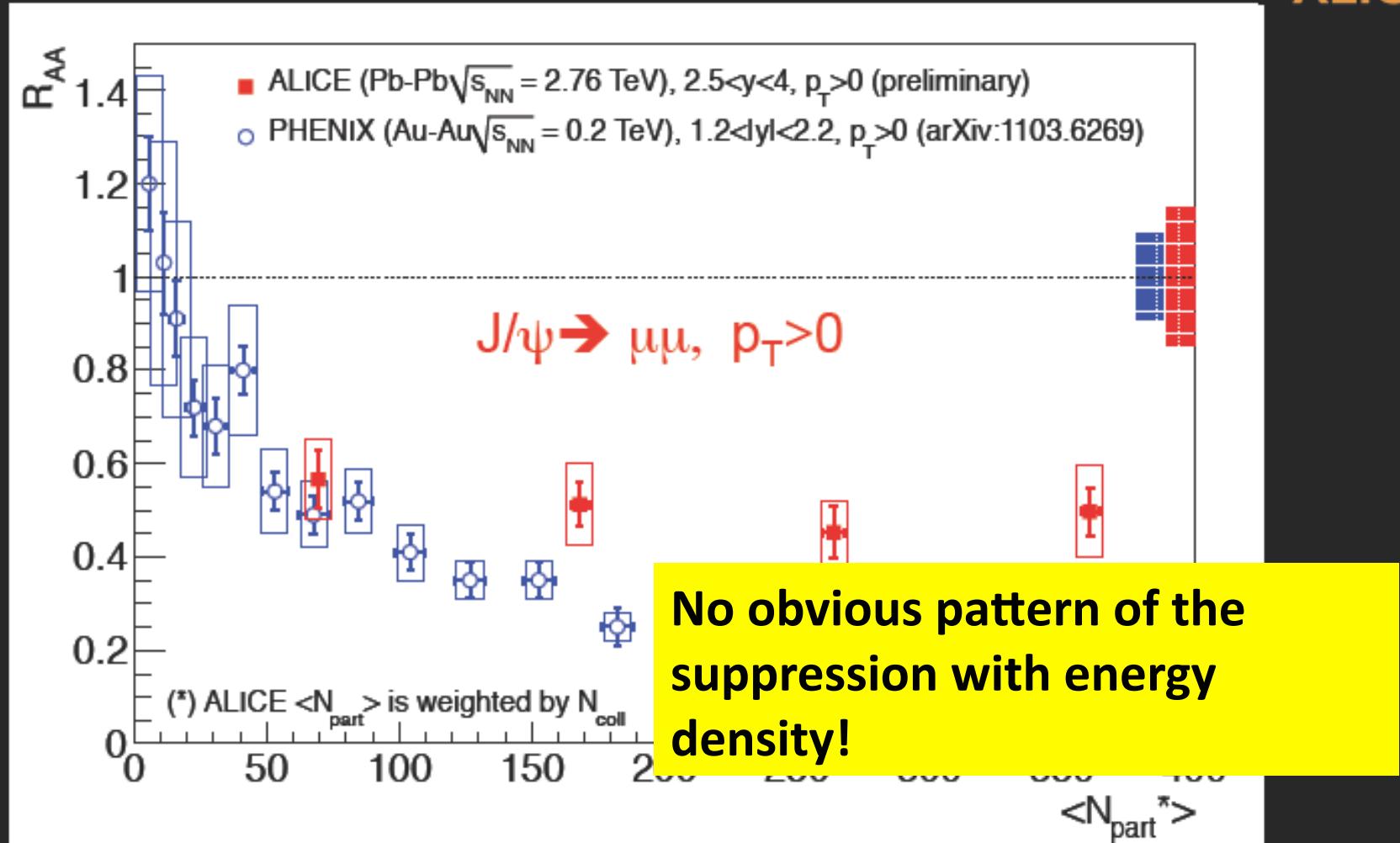
understand color screening:  
study as function of  $\sqrt{s}$ ,  $p_T$ ,  $r_{\text{onion}}$  +  
+Au to disentangle cold matter effects



# $J/\psi R_{AA}$ Centrality Dependence – LHC & RHIC



ALICE, G. Martinez-Garcia QM 2011



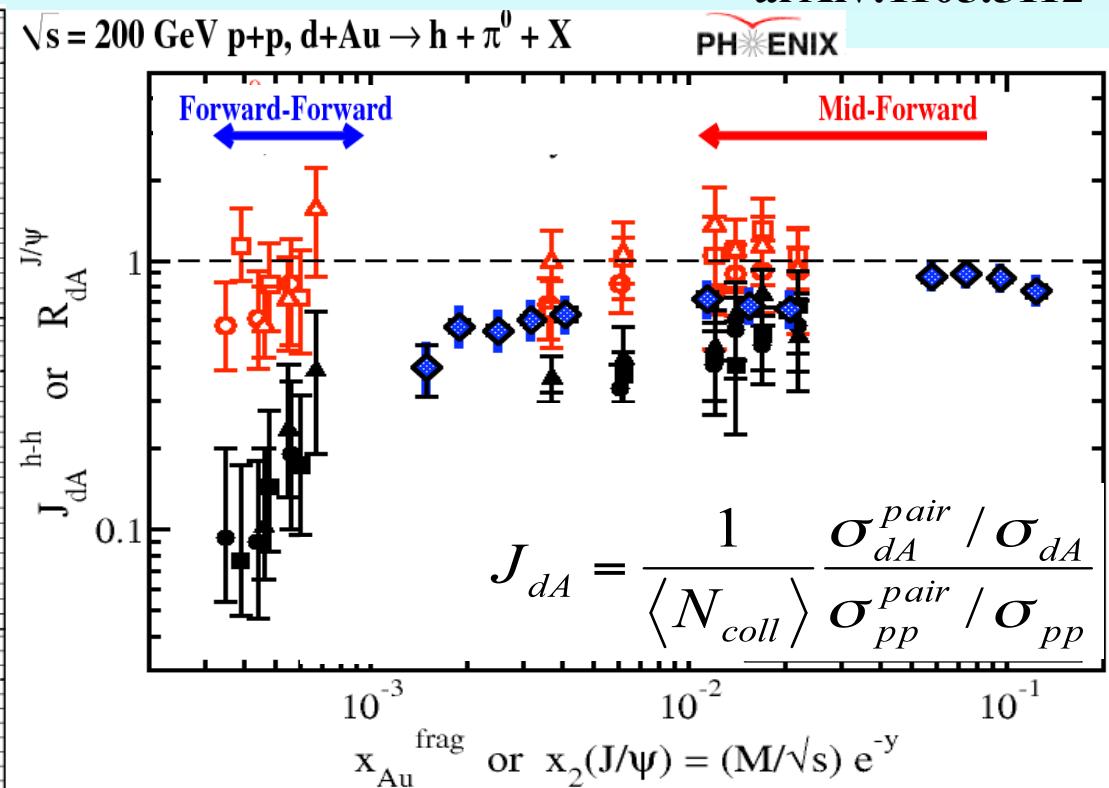
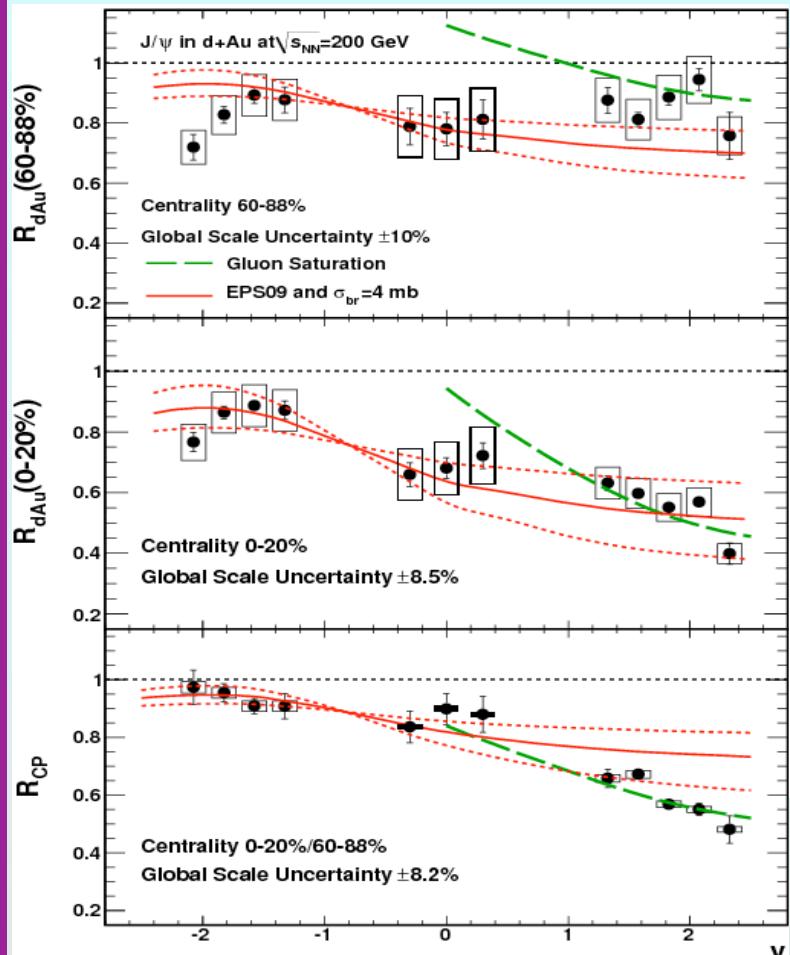
$J/\psi R_{AA}$  larger at LHC ( $2.5 < y < 4$ ) than at RHIC ( $1.2 < |y| < 2.2$ )

Similar to RHIC ( $|y| < 0.35$ ), except for most central bin

Note –  $dN_{ch}/d\eta(N_{part})^{LHC} \sim 2.1 \times dN_{ch}/d\eta(N_{part})^{RHIC}$

# Dense gluonic matter (d+Au, forward y): large effects observed

arXiv:1010.1246



Di-hadron suppression at low x  
pocket formula (for 2 → 2):

$$x_{Au}^{frag} = \frac{\langle p_{T1} \rangle e^{-\langle \eta_1 \rangle} + \langle p_{T2} \rangle e^{-\langle \eta_2 \rangle}}{\sqrt{s}}$$

Shadowing/absorption stronger than linear w/nuclear thickness



Toward NSAC milestone DM8

trend as, e.g. in CGC ...

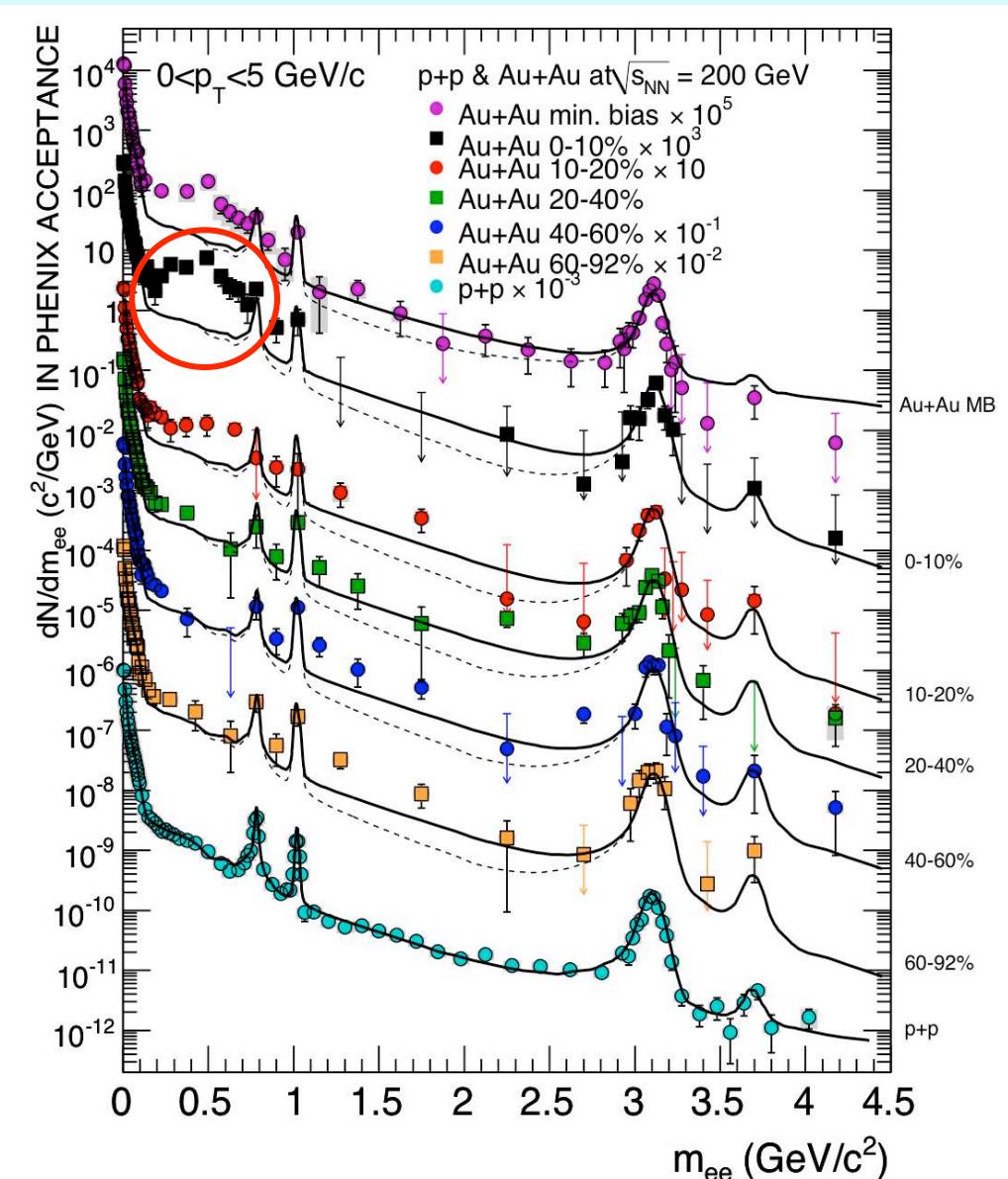


# Dielectron production in $0.5 < m_{ee} < 1 \text{ GeV}$

Significant excess in central collisions.

Dominantly at low  $p_T$

We are investigating using Run-10 data with the HBD



# Beam Energy Scan in PHENIX

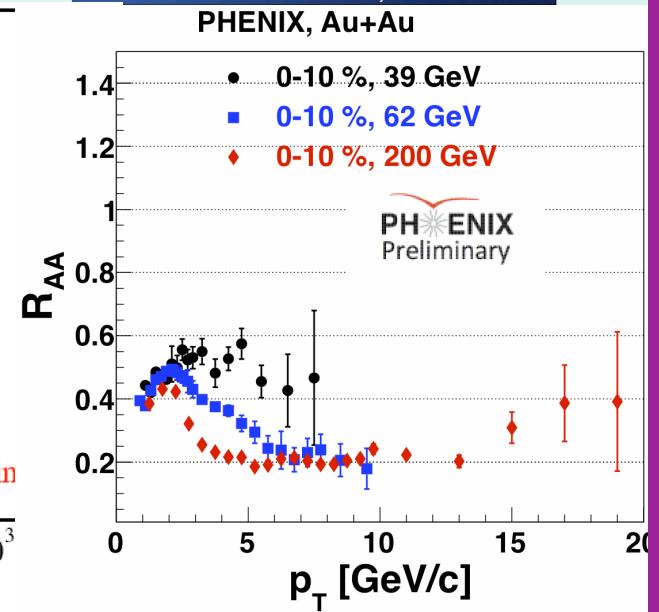
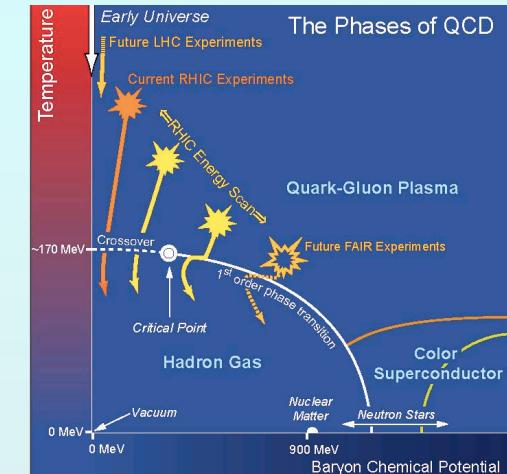
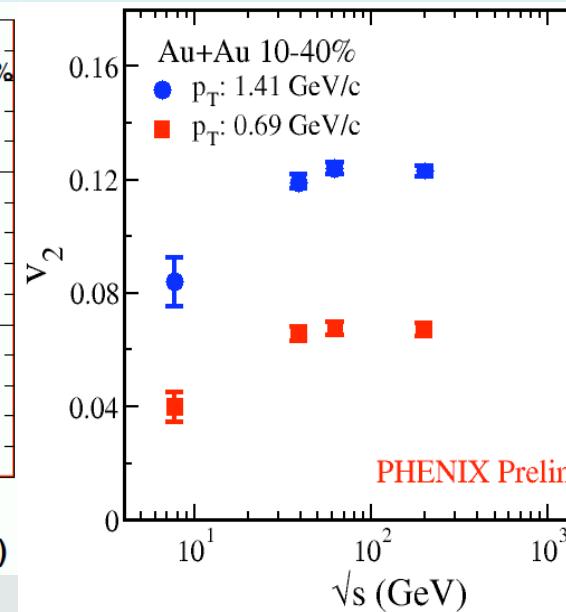
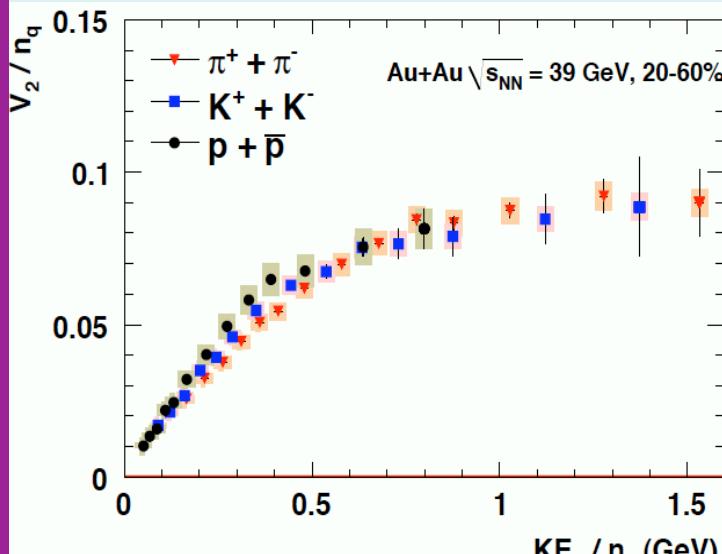
Is there a critical point separating 1<sup>st</sup> order phase transition & smooth cross-over?

- Quark-number scaling of  $V_2$

- saturation of flow vs collision energy
- find  $\eta/s$  minimum at critical point from flow

- Critical point searches via:

- fluctuations in  $\langle p_T \rangle$  & multiplicity
- $K/\pi$ ,  $\pi/p$ ,  $p\bar{p}/p$  chemical equilibrium
- $R_{AA}$  vs  $\sqrt{s}$ , ....



Toward NSAC milestone DM9

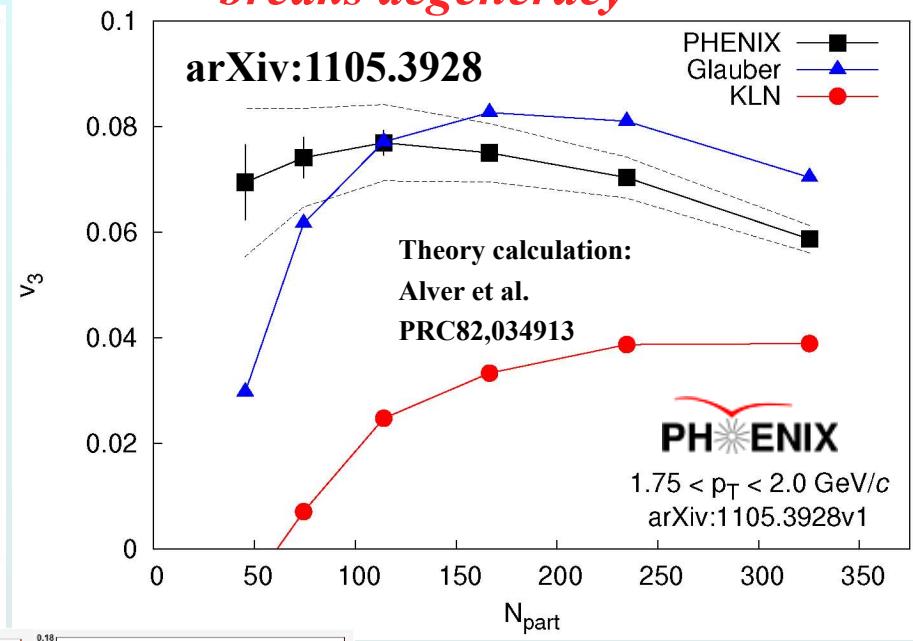
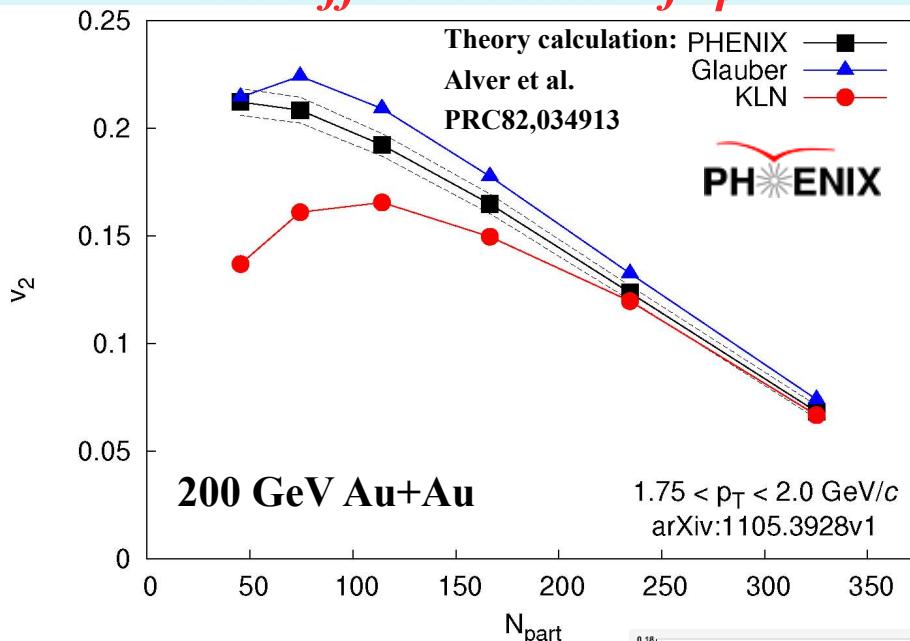


# Fluctuations, flow and the quest for $\eta/s$

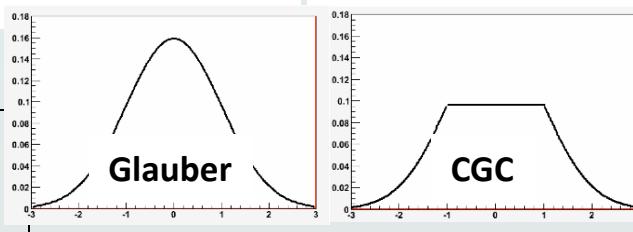
arXiv:1105.3928

$v_2$  described by both Glauber and CGC  
*but different values of  $\eta/s$*

$v_3$  described only by Glauber  
*breaks degeneracy*



- Glauber
- Glauber initial state
- $\eta/s = 1/4\pi$



Smaller eccentricity      Larger eccentricity

Lappi, Venugopalan, PRC74, 054905  
Drescher, Nara, PRC76, 041903

- MC-KLN
- CGC initial state
- $\eta/s = 2/4\pi$

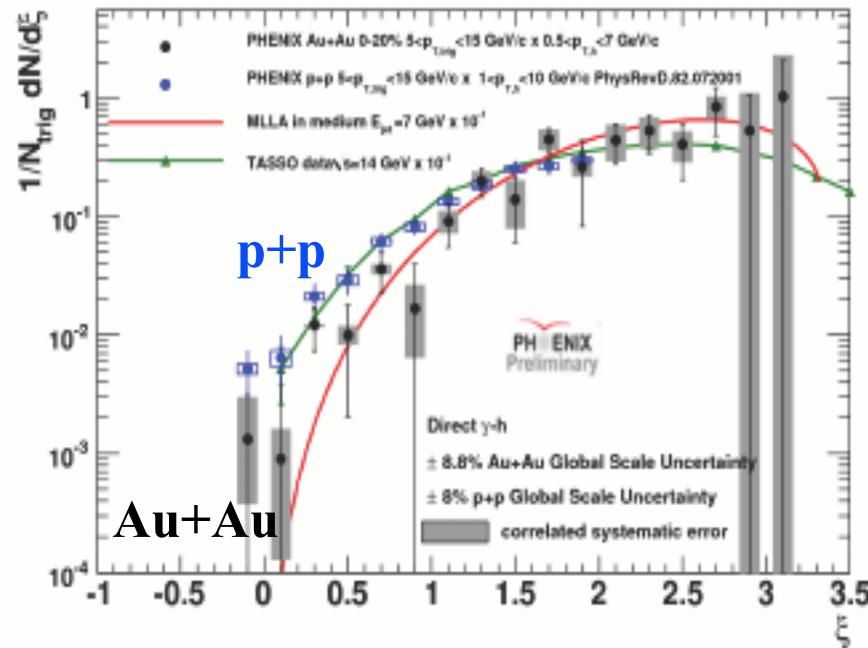


Toward NSAC milestone DM10



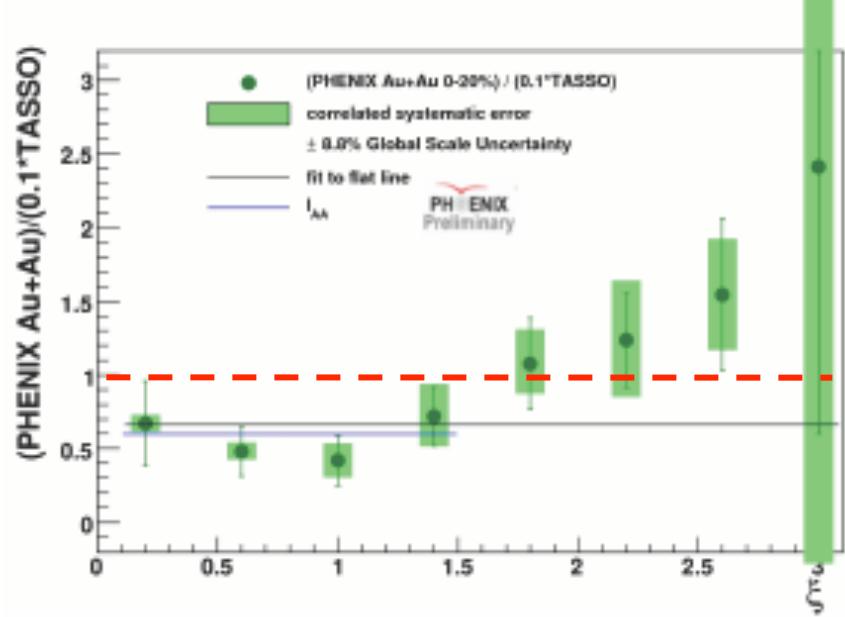
# $\gamma$ -jet correlations

Measure the fragmentation function



$$\xi = -\ln\left(\frac{p_T^h}{p_T^\gamma}\right)$$

Does QGP medium modify how q, g fragment into jets of hadrons?

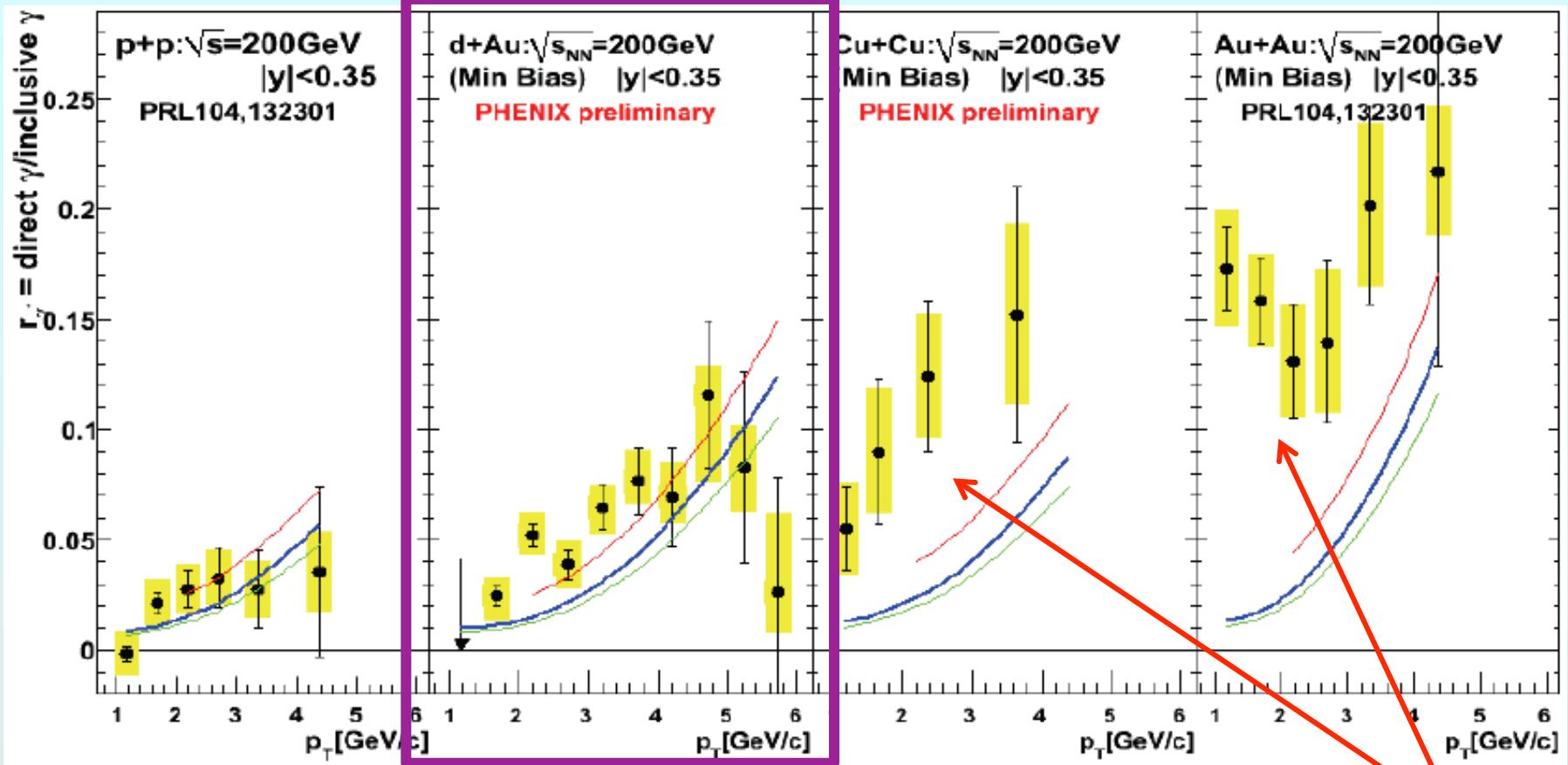


$$\langle I_{AA} \rangle = 0.662 \pm 0.087$$

$$\chi^2 / NDF = 12.16 / 7$$

Differs from that in  $e^+e^-$  collisions!

# Thermal photons (virtual)

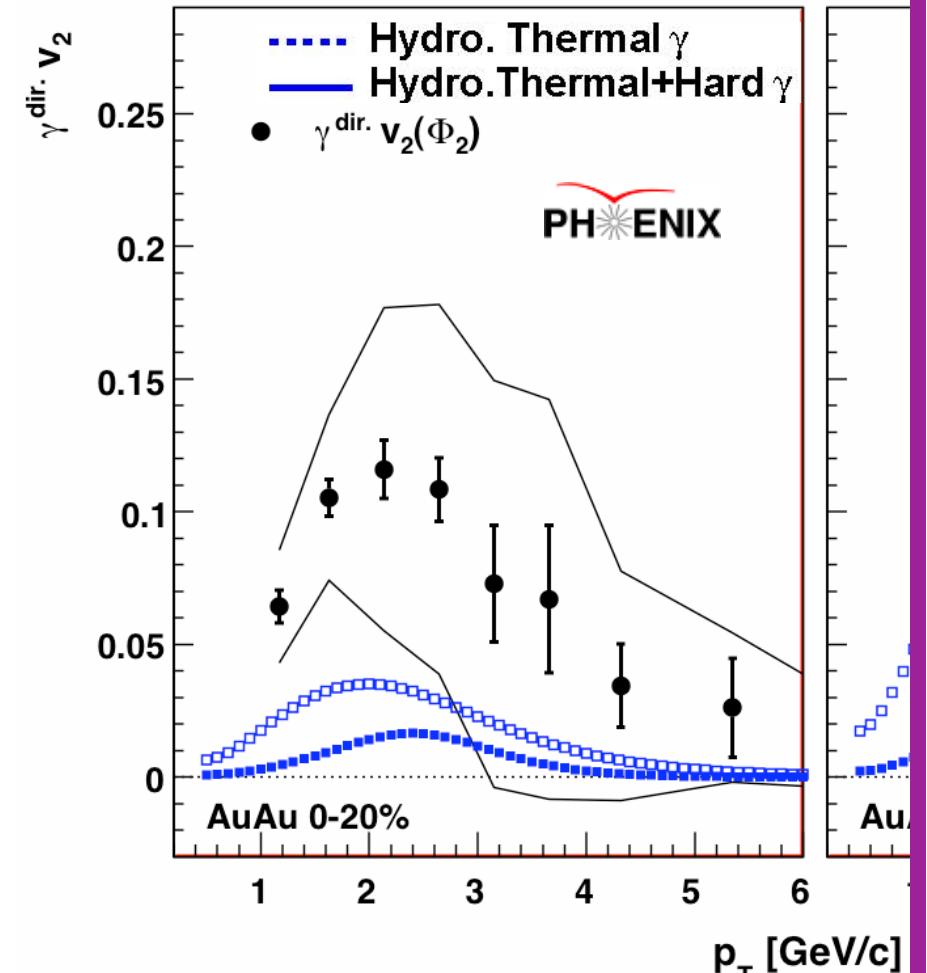
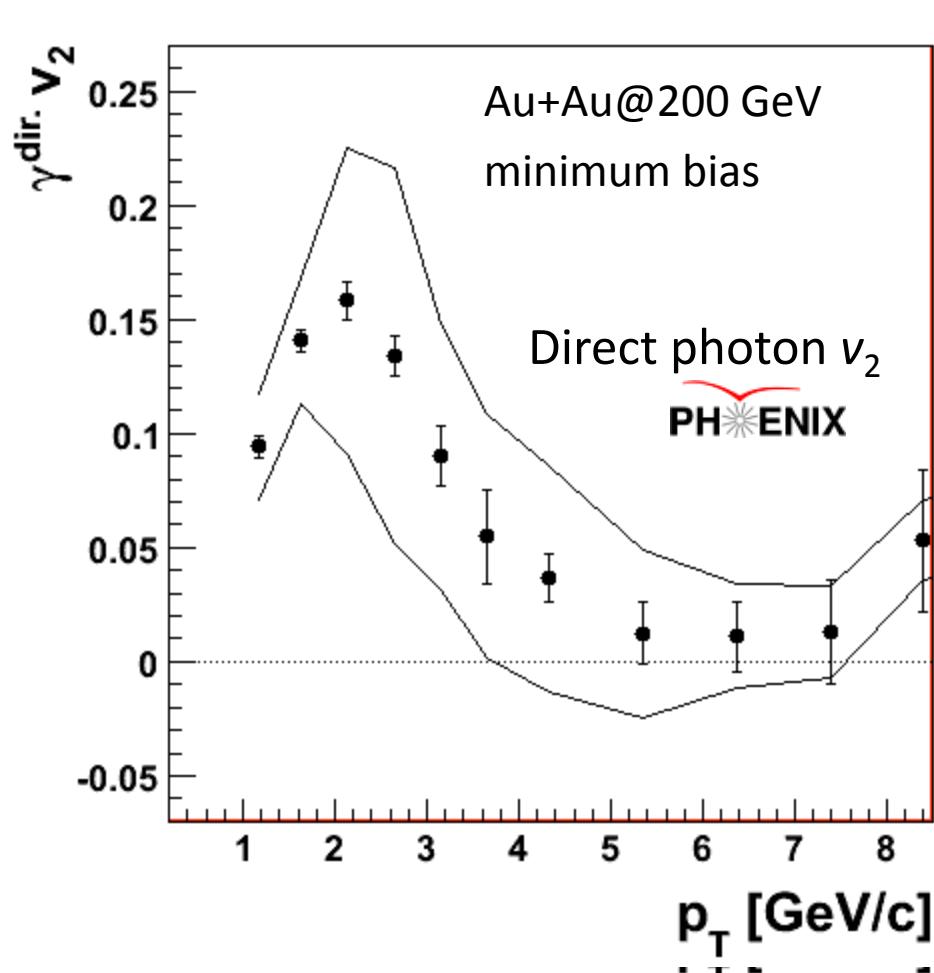


Observe excess photons beyond pQCD in AA collisions. In thermal  $p_T$  region

Toward NSAC milestone DM13

# Direct photons flow!

arXiv:1105.4126



Flow magnitude is a real surprise!

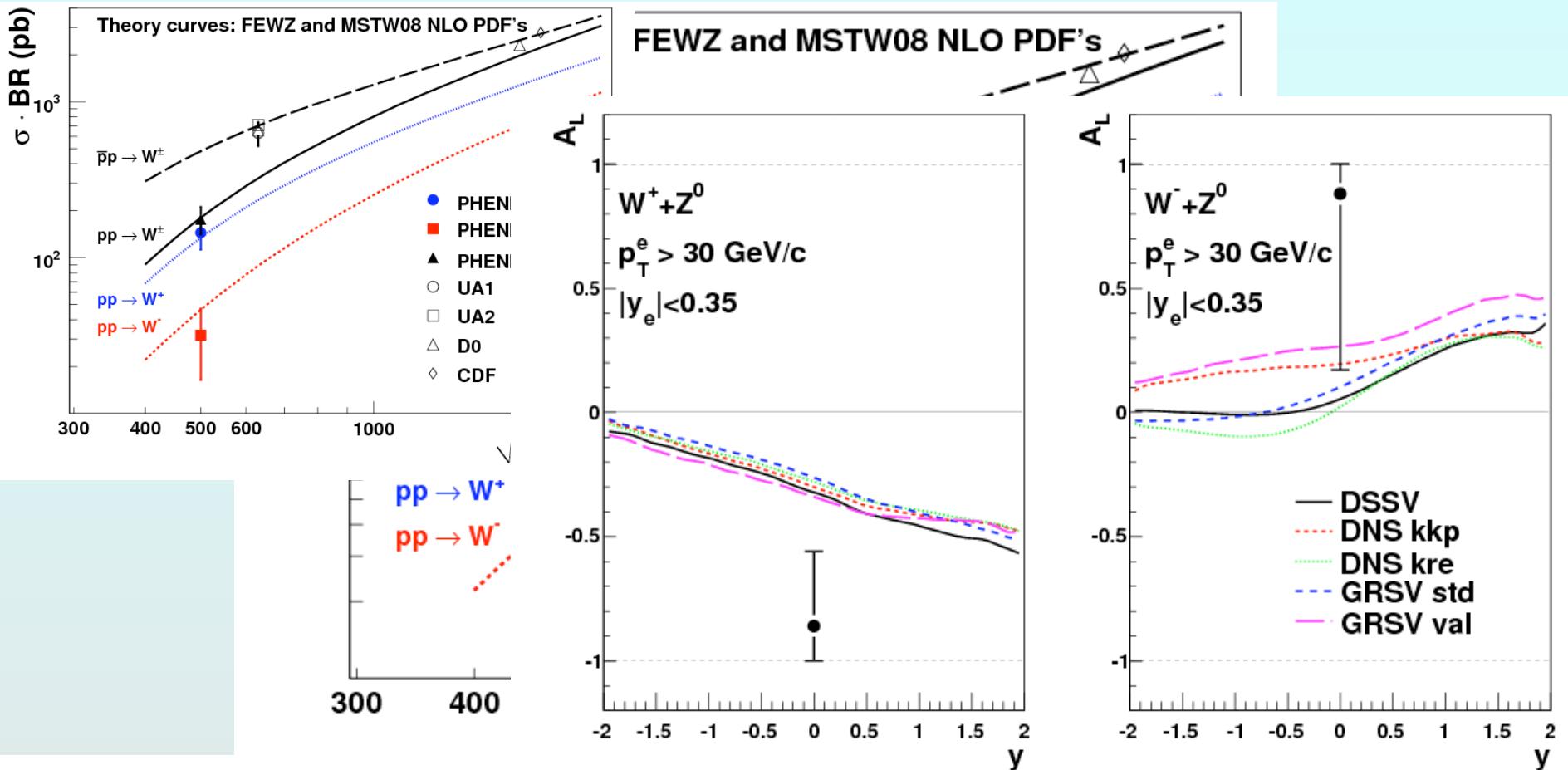
Stefan Bathe for PHENIX, QM2011

22



Toward NSAC milestone DM13

# First publication of W's at RHIC



PRL106, 062001(2011)

- Measure  $\sigma$ , first look at  $A_L$  with electrons in Run-9
- Starting with Run-11: precision  $W \rightarrow \mu$

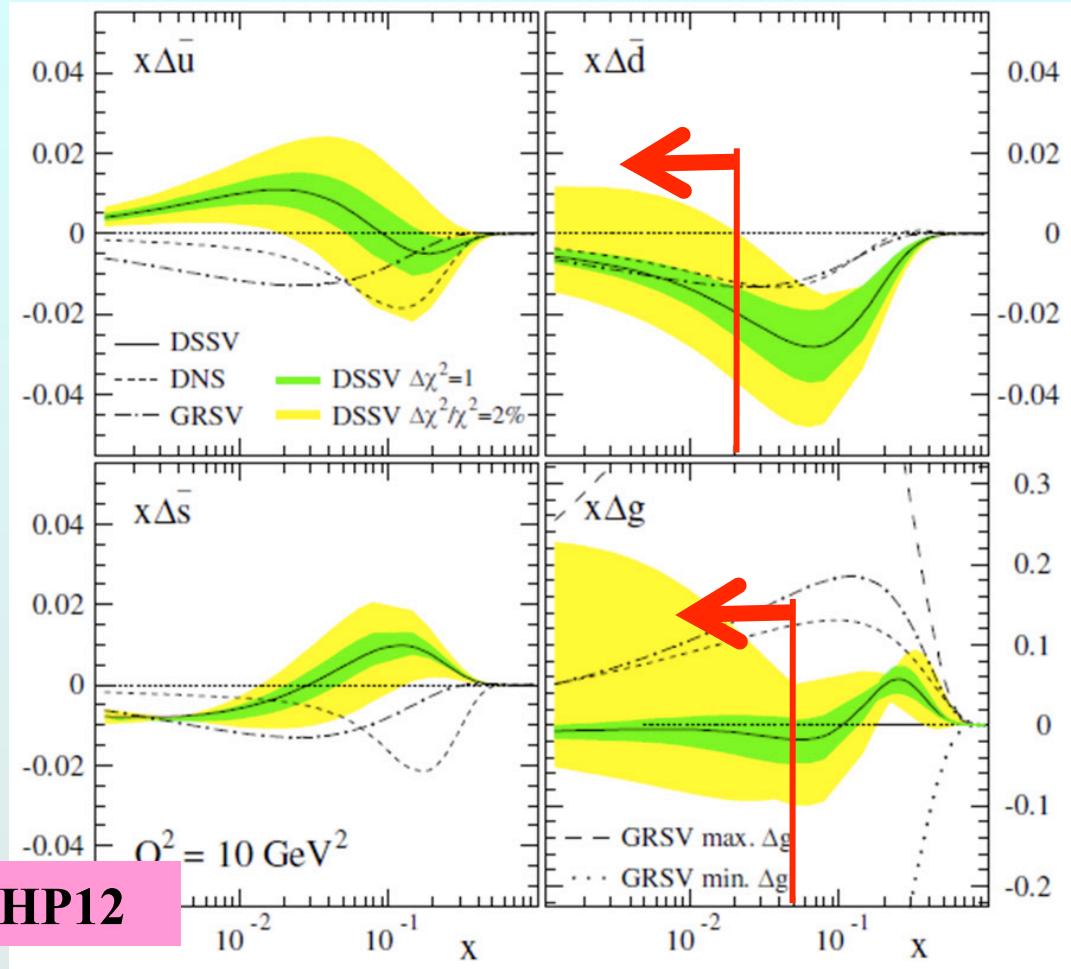
# gluon & sea quark polarization

*Current result  
from global fits*

*Still surprisingly  
small*

*See talk from Elke  
Aschenauer*

Toward NSAC milestone HP12

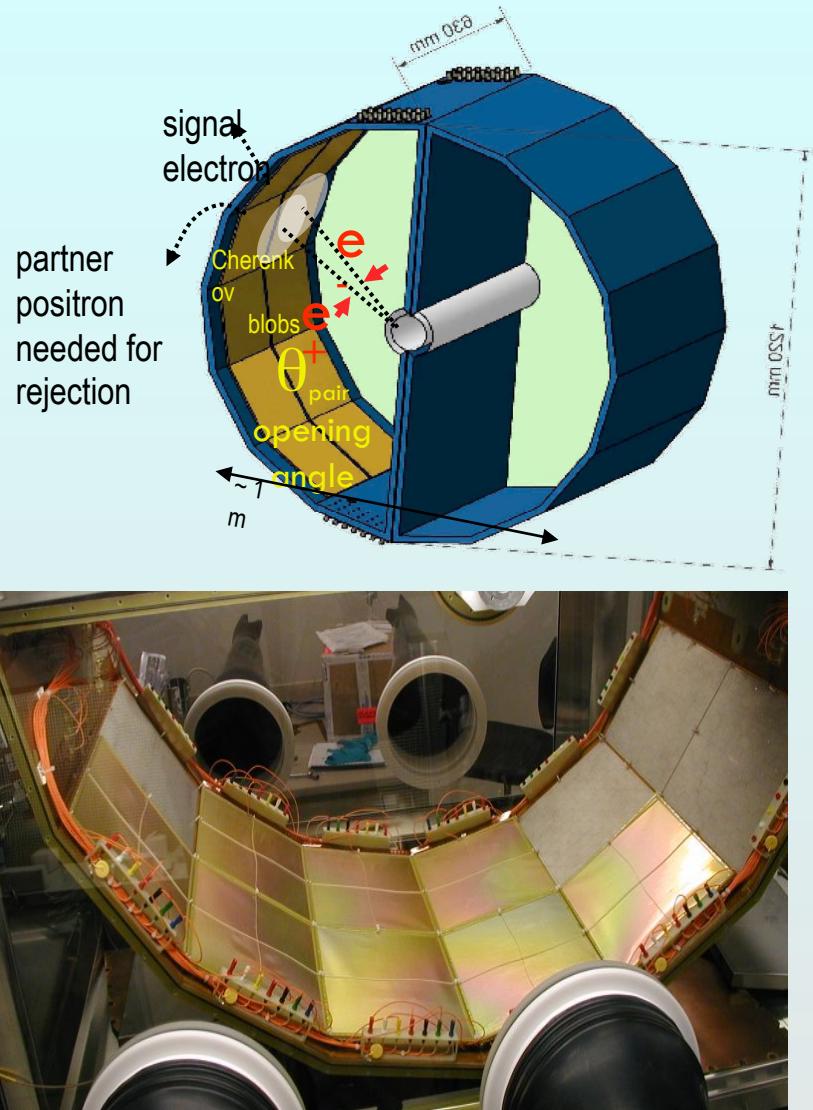


- 500 GeV p+p:  $\pi^0 A_{LL}$  to constrain  $\Delta g$  ( $0.01 < x < 0.3$ )  
central/forward correlations tag kinematics
- W  $A_L$  at forward, backward, mid rapidity for  $\Delta u^- \Delta u, \Delta d^- \Delta d$

**PHENIX has regularly upgraded our detector**  
**new capabilities -> new, exciting physics**

**most every year (!)**

# HBD: data analysis is underway



|                                    |                             |
|------------------------------------|-----------------------------|
| $N_0$ ideal value                  | 714 cm <sup>-1</sup>        |
| Optical transparency of mesh       | 88.5 %                      |
| Optical transparency of photocath. | 81.0 %                      |
| Radiator gas transparency          | 89.0 %                      |
| Transport efficiency               | 80.0 %                      |
| Reverse bias and pad threshold     | 90.0 %                      |
| $N_0$ calculated                   | 328 +/- 46 cm <sup>-1</sup> |
| $N_{pe}$ expected                  | 20.4 +/- 2.9                |
| $N_{pe}$ measured                  | 20                          |
| $N_0$ measured value               | 330 cm <sup>-1</sup>        |

The highest ever measured  $N_0$ !

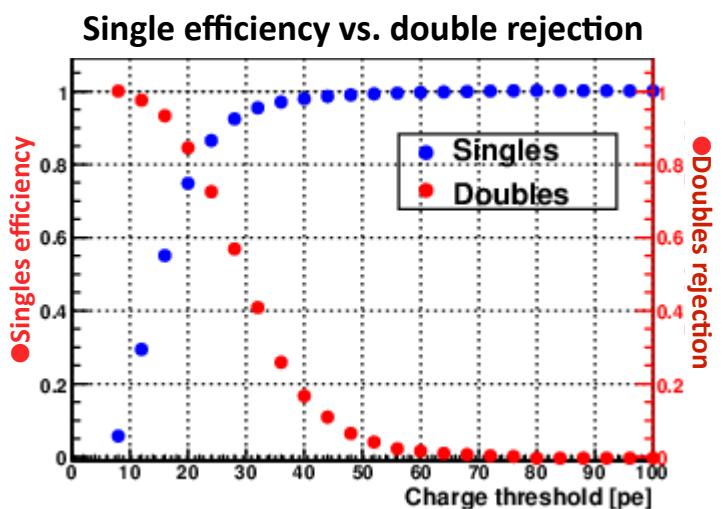
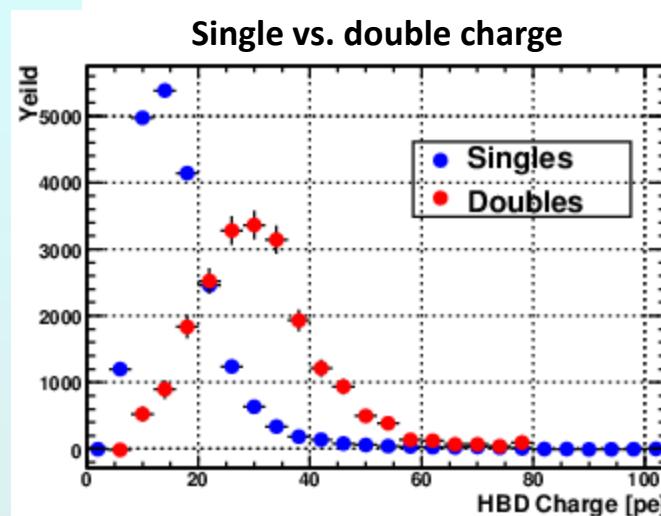
Maintained for 2 years

- Single electron charge peaks at 20 pe
- Double electron charge peaks at ~40 pe
- Good single to double separation

# In central Au+Au, must deal with scintillation light. rejection of $\pi^0$ Dalitz electrons and upstream conversions

- ❖ Subtract  $\langle pe \rangle$  to reject scintillation  $\gamma$
- ❖ Then, can reject upstream conversions and  $\pi^0$  Dalitz pairs with single/double charge cut
- ❖ This requires good gain calibration throughout the entire run
- ❖ Single electron hits studied w/ MC  
 $\phi \rightarrow e^+e^-$  embedded in Au+Au data
- ❖ Double electron hits studied using MC  
 $\pi^0 \rightarrow \gamma\gamma$  embedded in Au+Au data
- ❖ Background normalization underway

Run 10 Au+Au  $e^+e^-$  pair spectrum soon



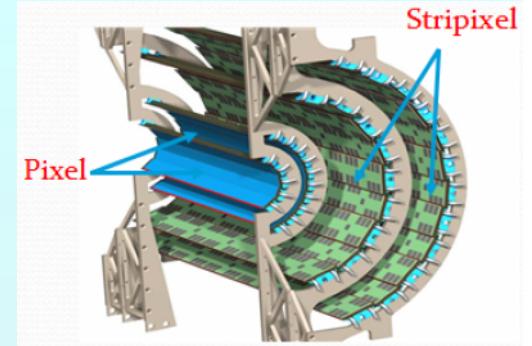
# Mysteries in heavy ion physics

- ◆ Energy loss mechanism NSAC milestone DM11, 12
    - @ LHC 40 GeV jets opposing 100 GeV jets look “normal”
      - no broadening or decorrelation
      - no evidence for collinear radiation from the parton
    - @ RHIC low energy jets appear to show medium effects
      - but, “jet” is defined differently
    - c & b to probe role of collisional energy loss **VTX, FVTX**
    - quantify path length dependence **U+U, Cu+Au**
  - ◆ J/ $\psi$  suppression and color screening NSAC milestone DM5
    - amazingly similar from  $\sqrt{s}=17\text{-}200 \text{ GeV}$ ; but initial states differ not SO different at LHC
    - Other states y &  $\sqrt{s}$  dependence (e.g.  $\psi'$ ) **FVTX, statistics**
    - d+Au for initial state; 130 GeV Au+Au eventually?



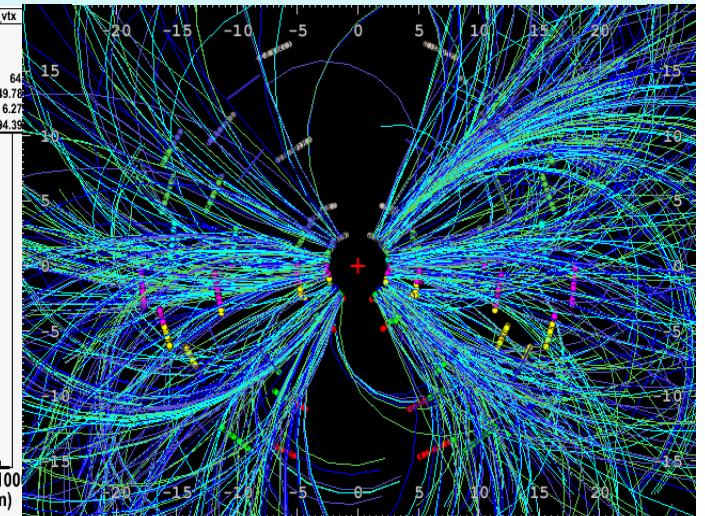
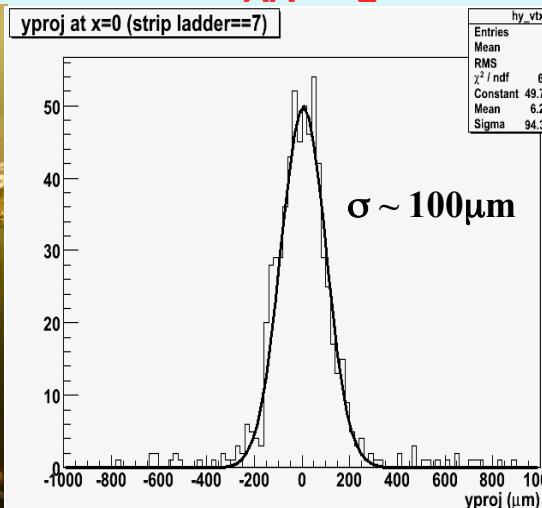
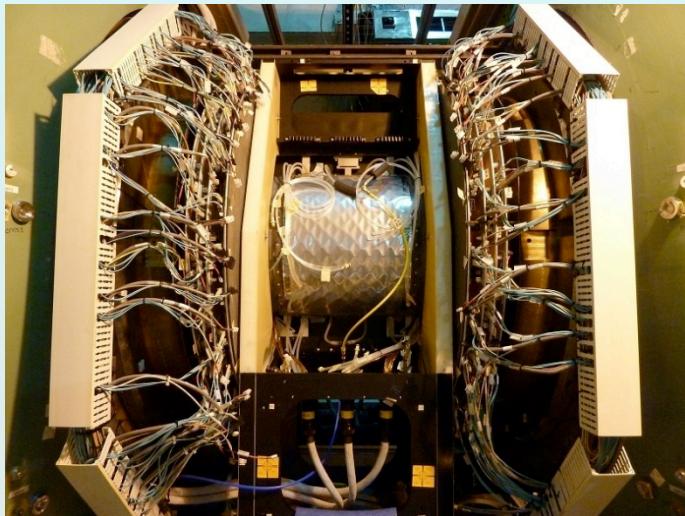
# VTX is installed and commissioned

- *GOAL: Complete and take data in Run-11*



- Successfully commissioned in 2011 p+p run
- Taking data in Au+Au now

Opens era of c/b separated  $R_{AA}$ ,  $v_2$  at RHIC    Au+Au@200 GeV, 2011



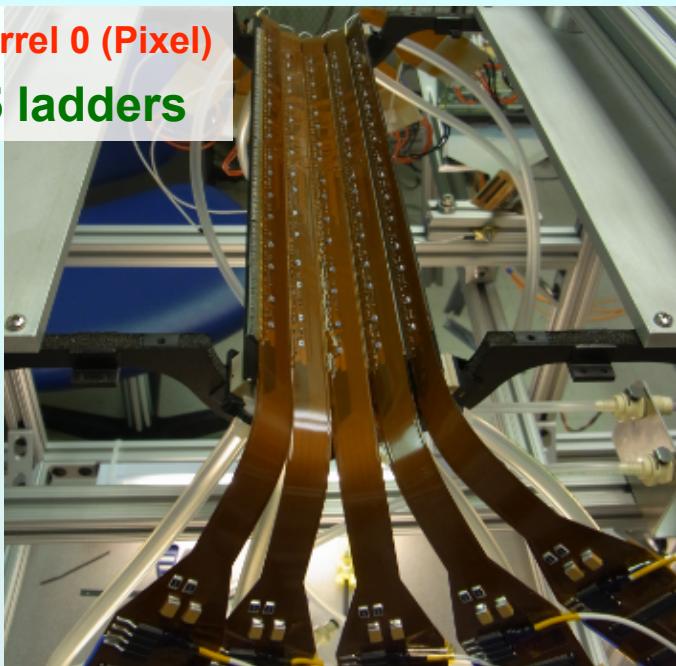
- *The goal was met! (on budget) VTX is a success!!*



# A peek inside the VTX

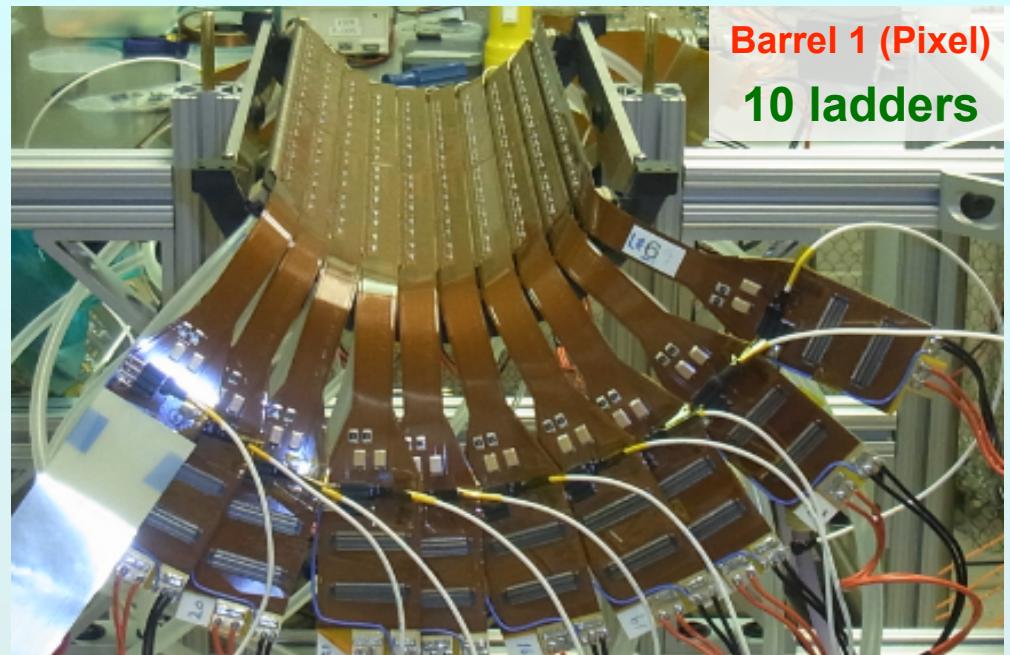
Barrel 0 (Pixel)

5 ladders



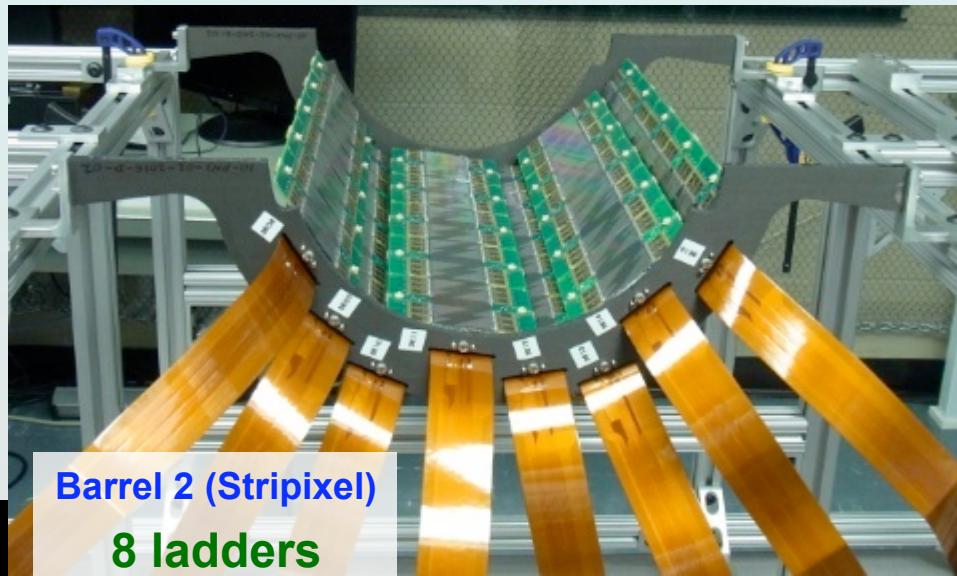
Barrel 1 (Pixel)

10 ladders



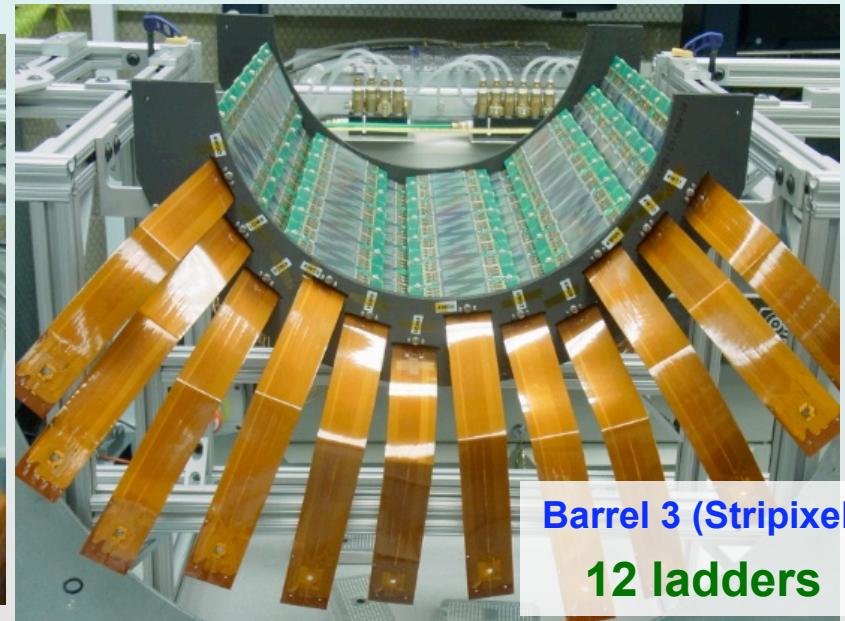
Barrel 2 (Stripixel)

8 ladders

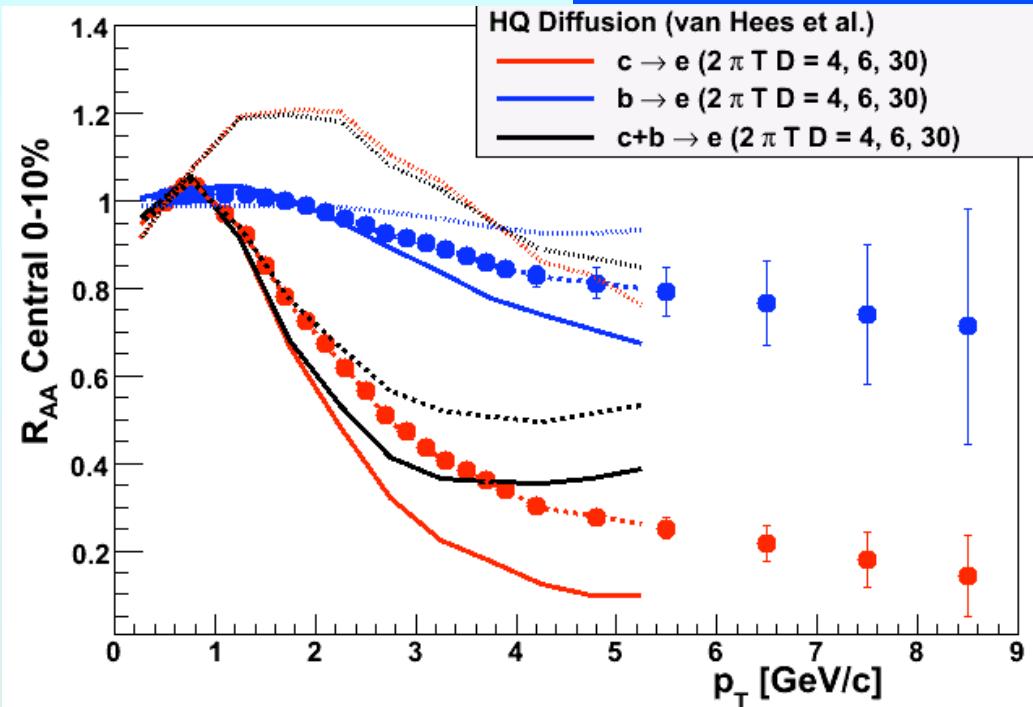


Barrel 3 (Stripixel)

12 ladders

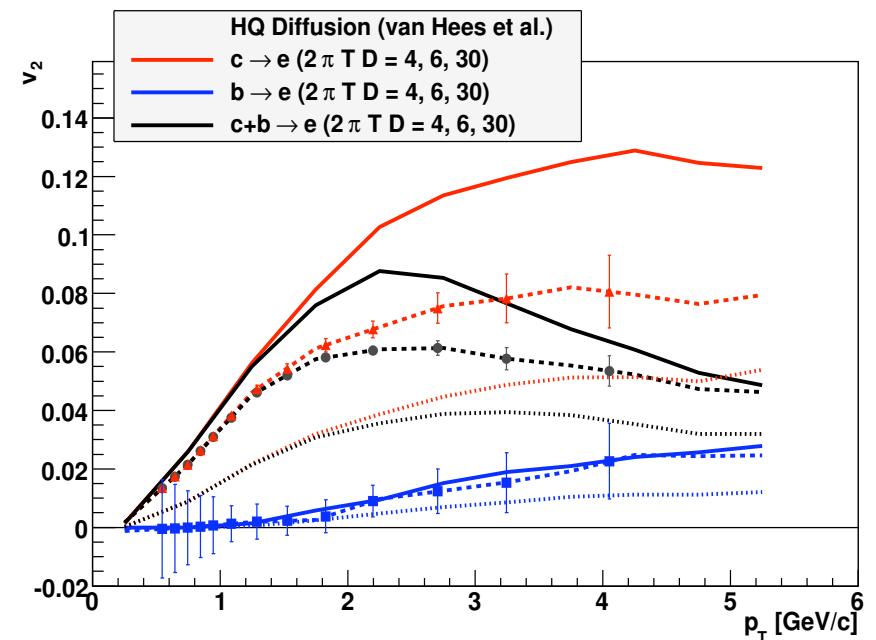


# How well we will do



For 29M mb Au+Au events  
7 weeks in Run-13:  $0.8 \text{ nb}^{-1}$   
(~4B events) in 10cm  
Error bars Run-13 alone:  $\times \sqrt{6}$   
 $c, b R_{AA}$  to  $\sim 5 \text{ GeV}/c$   
 $b v_2$  to  $\sim$  a few  $\text{GeV}/c$

*Statistical power of VTX data  
from Run-11 is not yet known*

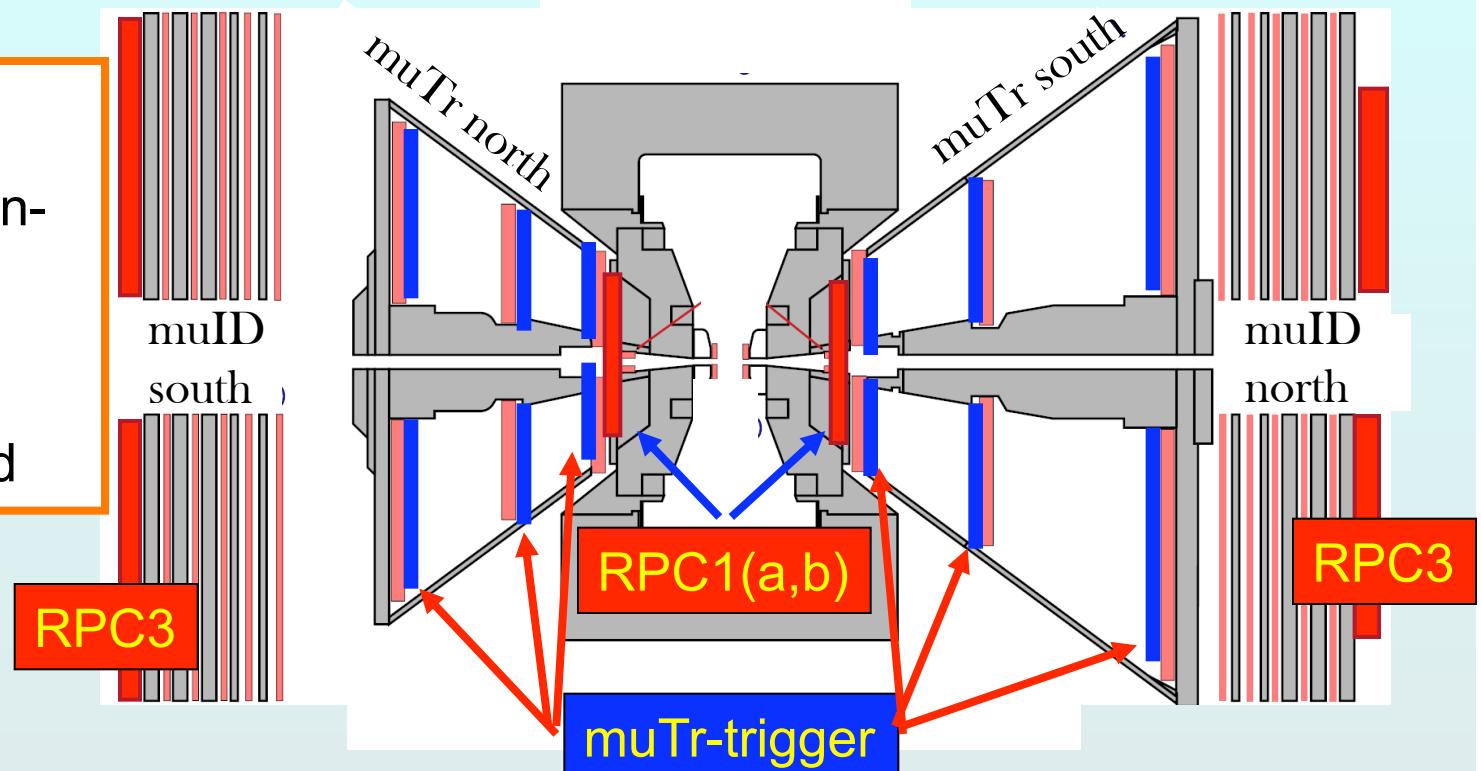


# Muon Trigger Upgrade

## Trigger idea:

Reject low momentum muons

Cut out-of-time beam background



## Upgrade:

o muTr trigger electronics: muTr 1-3 → send tracking info to level-1 trigger

o RPC stations:

*muTr FEE + RPC3 took data in Run-11*

*RPC1's to be installed for Run-12*

## Muon arm background reduction

Stainless steel SS-130 absorbers, 12 tons each side (!)

2 interaction lengths, based upon simulations



Installed on both muon arms during 2010 shutdown

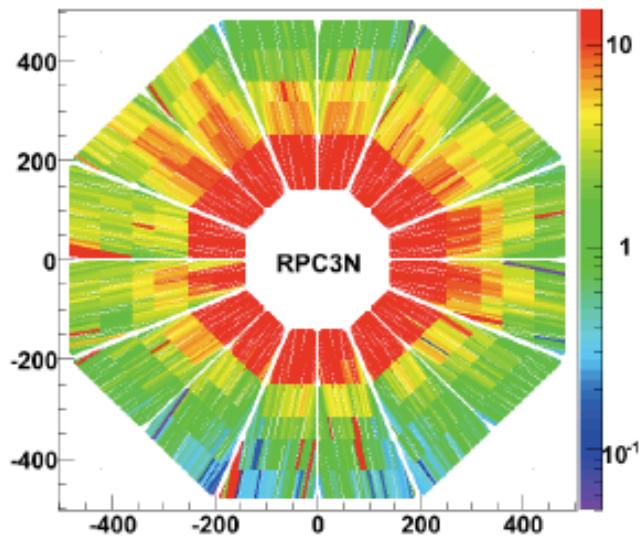
# Muon trigger status, first look at Run-11 data



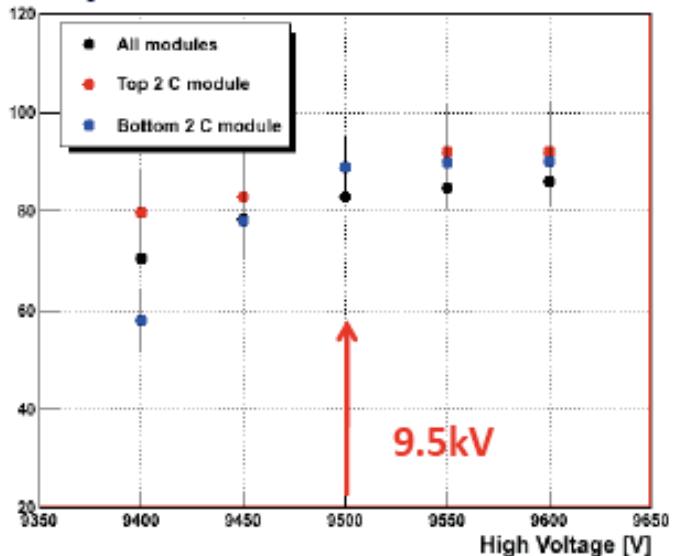
*Rejection power  
~1100 @ 2.7MHz  
S/B~1/2 first look  
Anticipate 3/1 after  
tuning*

**PHENIX**

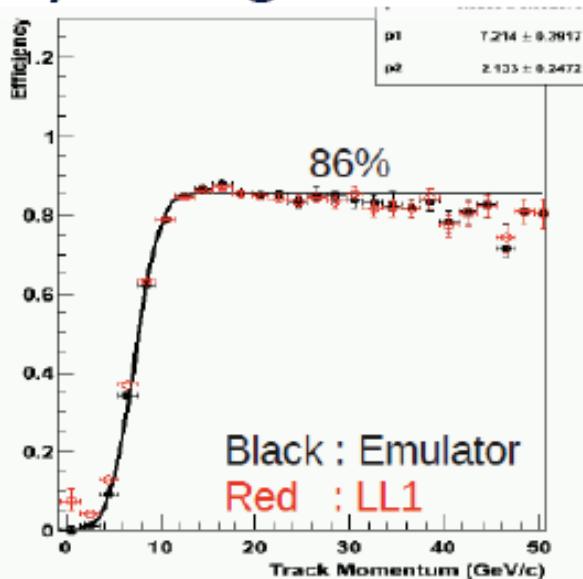
a) RPC Hit Map



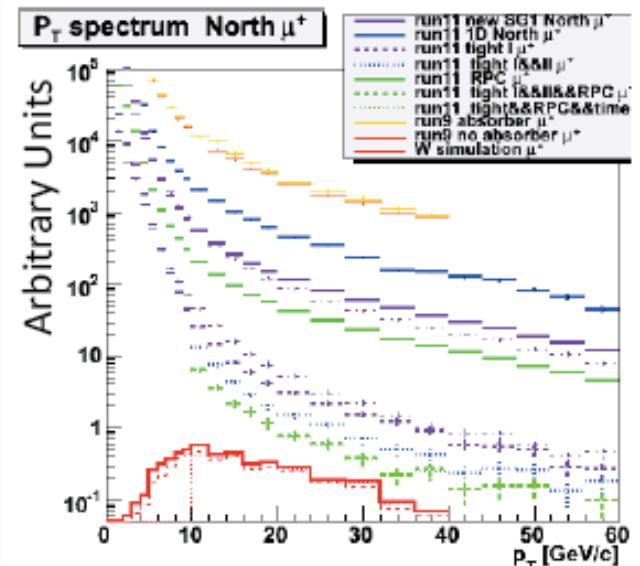
b) RPC-3 Efficiencies



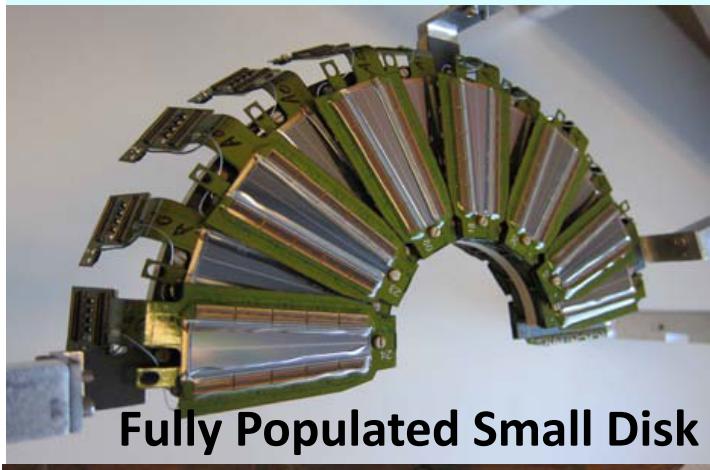
c) MuTrig-Efficiencies



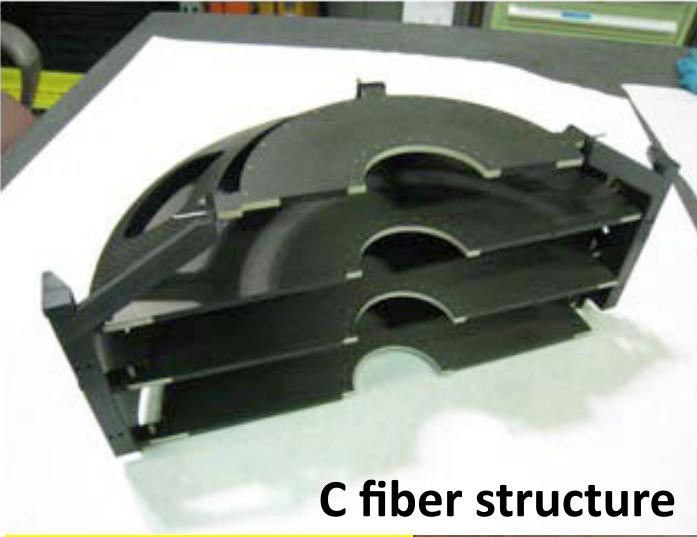
d) High  $p_T$  Background



# FVTX construction underway



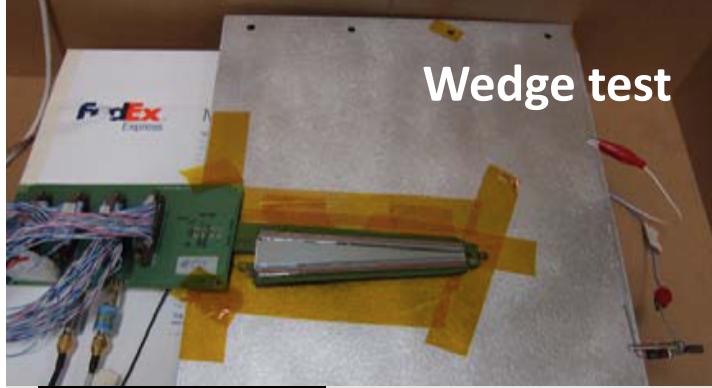
Fully Populated Small Disk



C fiber structure



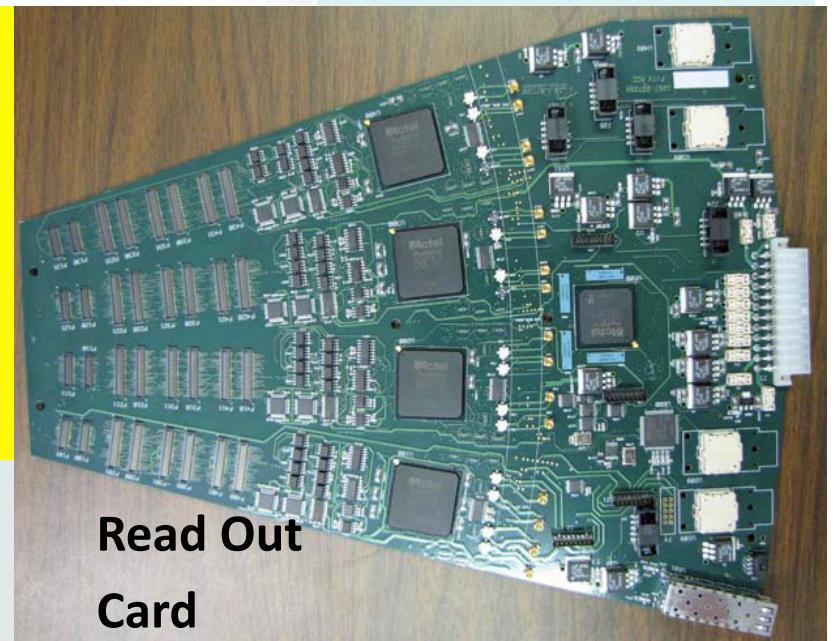
Fully Populated Large Disk



Wedge test

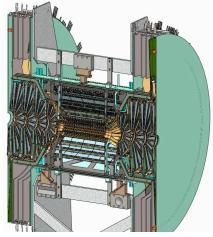
→ Forward y  
• open heavy flavor physics  
•  $\psi'$  in AuAu & dAu

*On track  
to install for Run-12*



Read Out Card





# Forward Silicon Vertex Detector

## Detector Assembly

Assembly: 96 small, 288 large silicon wedges mostly complete  
14 out of 16 silicon disk assemblies completed  
Assembly of disks into four half-cages about to begin

## Readout System

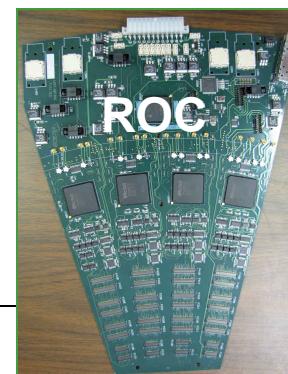
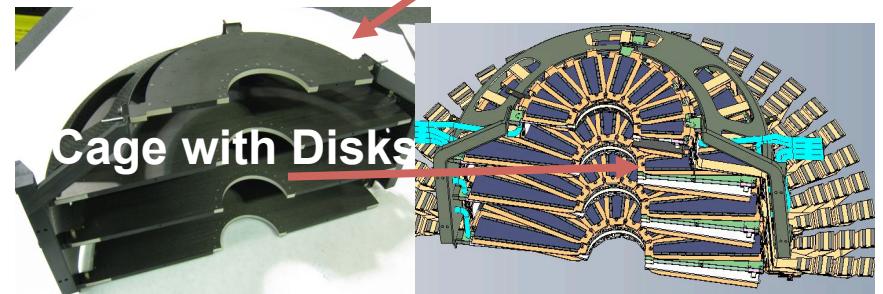
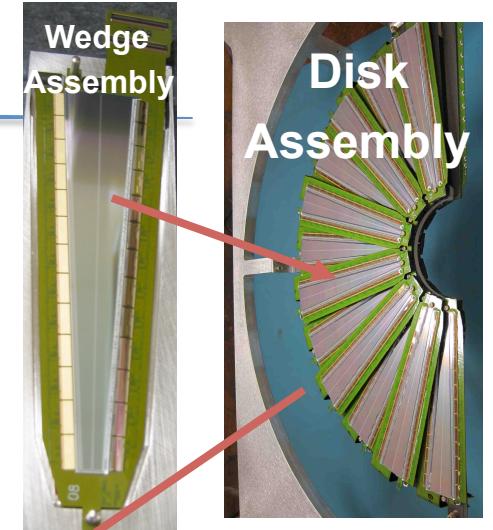
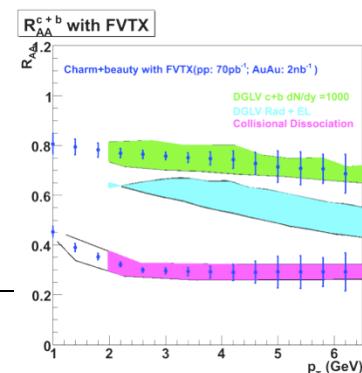
Boards prototyped, production cards received or in procurement  
All design specifications met!

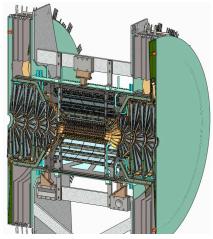
## Mechanics

All detector mechanical structures completed

## Schedule

Detector assembly expected complete by August  
Integrate FVTX and VTX & install into PHENIX  
Data collection in Run 12





# Full Chain Tests Successful

Disk read out with overlapping wedges  
powered simultaneously

No measured cross-talk among wedges

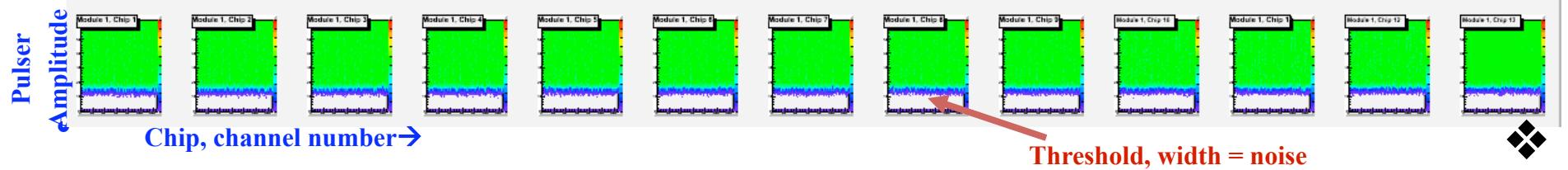
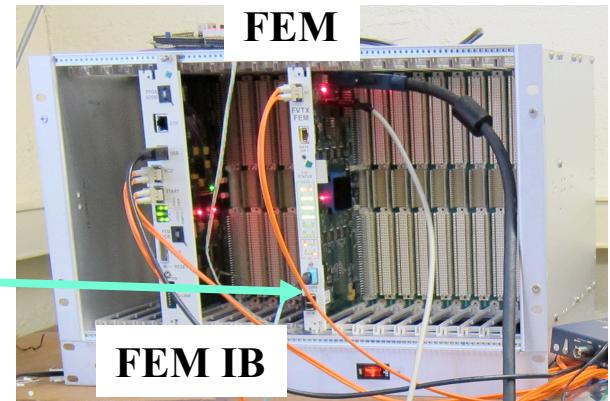
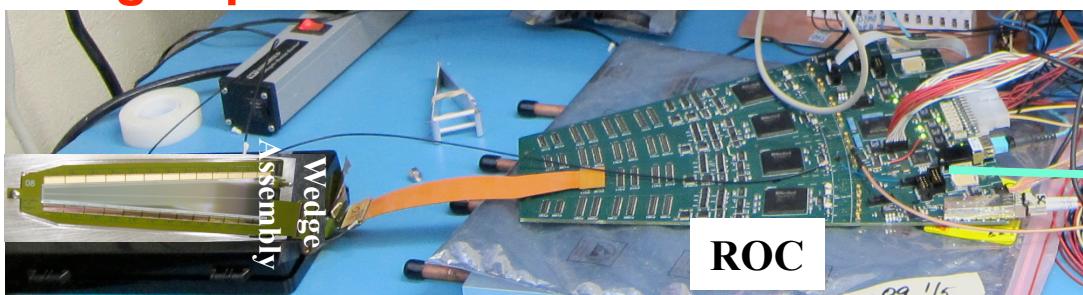
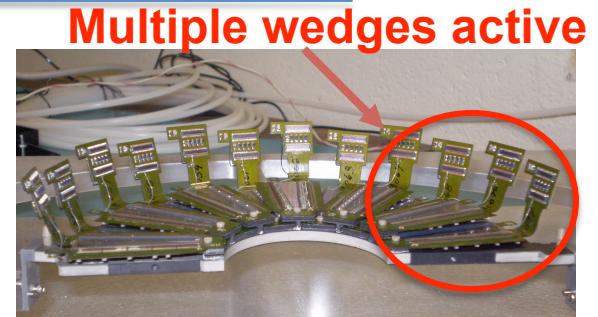
Noise specifications maintained with full activity in wedges

## Full DAQ Chain Test Performed

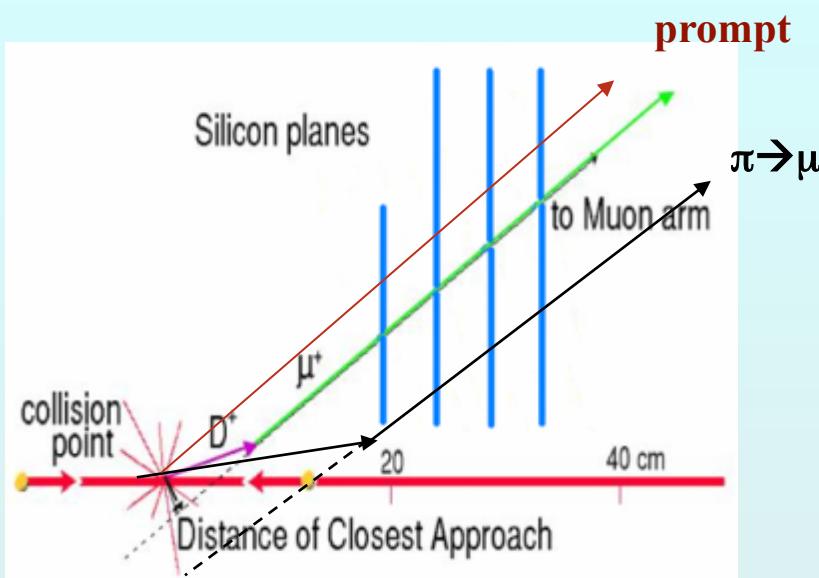
Production wedge → kapton extension cable → ROC → FEM

Production LV and HV power distribution system used

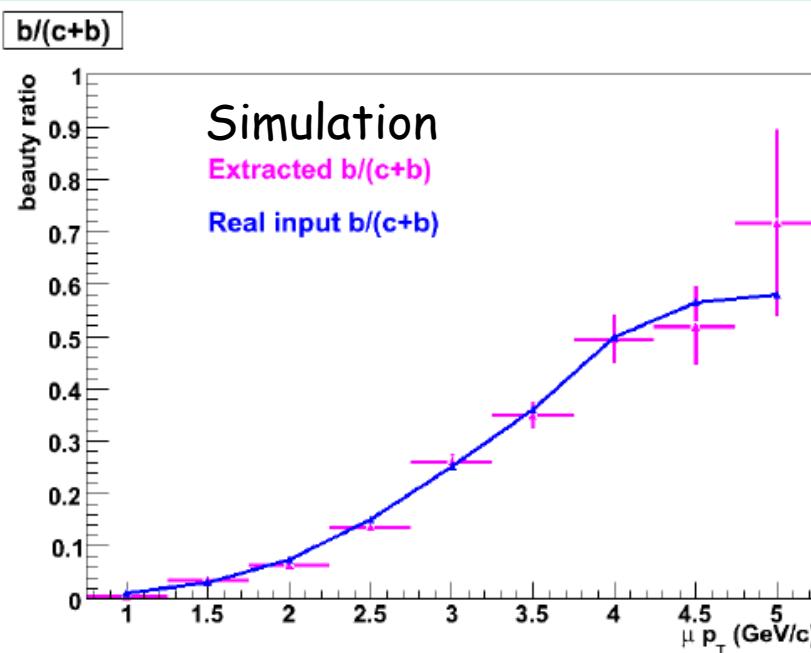
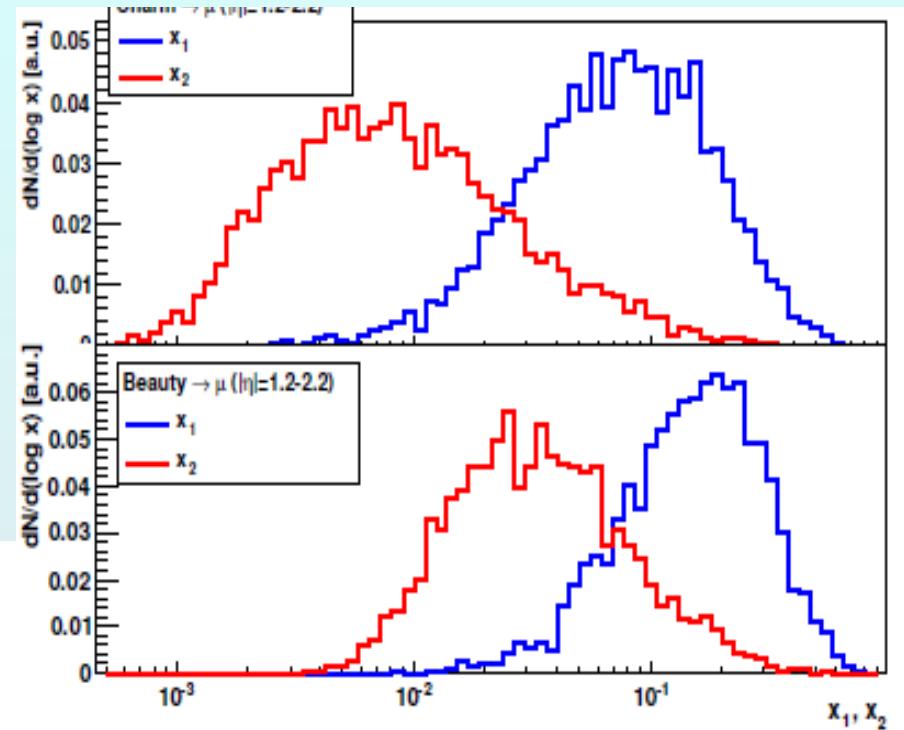
**Full data collection chain works,  
design specifications met!**



# FVTX performance simulations



c,b coverage



Fit DCA distribution in each  $p_T$  bin with sum of individual c, b contributions.  
Iterate to constrain D and B  $p_T$  distributions.

# Near term: MPC extension

Enhance forward rapidity ( $3 < \eta < 3.8$ )

preshower & tracking detectors

- direct photons

- $\pi^0$ 's to high  $p_T$ ; jet direction w/ charged hadrons

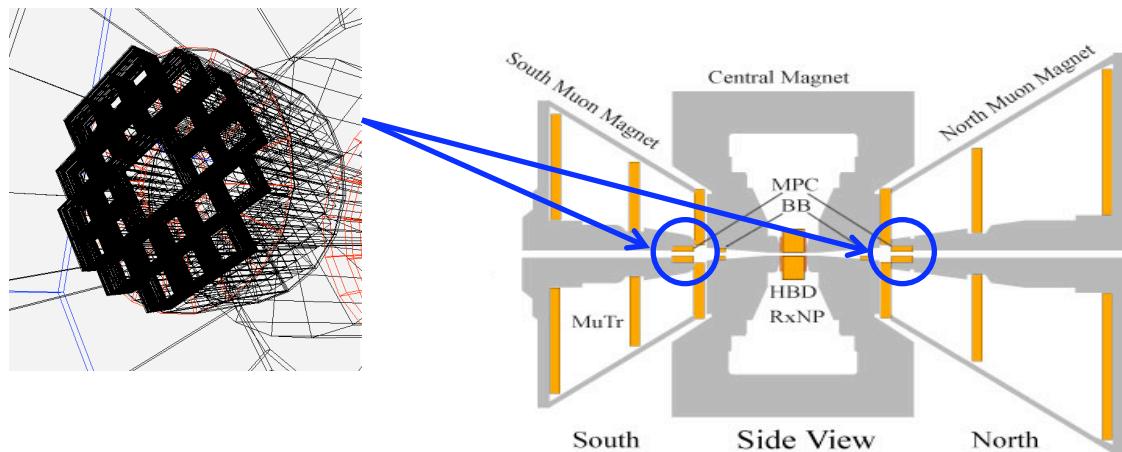
- $J/\psi$  in MPC

Silicon/W technology (pads & 500  $\mu\text{m}$  strips)

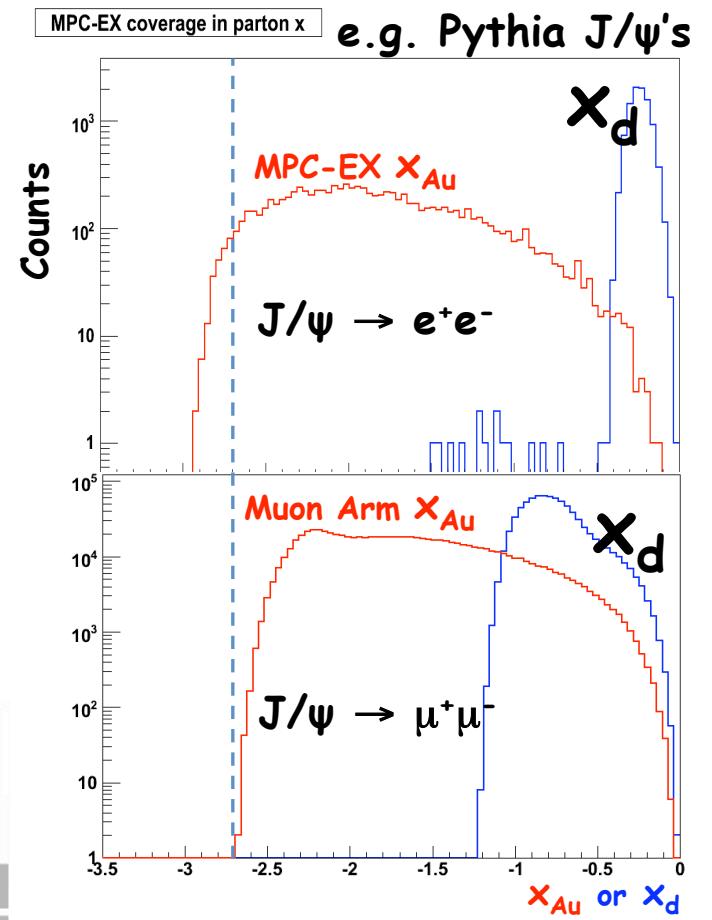
$J/\psi$  acceptance:

$260 \text{ nb}^{-1} d+\text{Au}: \sim 9.7\text{k } J/\psi \rightarrow e^+ e^- \text{ in North MPC}$

$34 \text{ pb}^{-1} 200 \text{ GeV p+p}: \sim 3.6\text{k } J/\psi \text{ sum for two arms}$



6/21/2011



Ready for next  
 $d+\text{Au}$  Run!  
(2014?)

# Project Management Approach

- **For all upgrades:**
  - Monthly reporting to PHENIX Detector Council
  - PHENIX Management attendance at weekly project group meeting
  - Continuous e-mail contact with PHENIX Management on project issues
  - Status, plans, issues discussed in weekly PHENIX Management meeting*
- **DOE+BNL Managed projects (VTX+FVTX)**
  - Annual external reviews*
  - Quarterly financial + monthly technical phone conferences w/ BNL+DOE*
  - Weekly reporting at PHENIX Planning meeting during final 12 months of project  
(BNL-PHENIX Ops group)
- **BNL-PHENIX Managed projects (MuTrg)**
  - Initial review by external expert committee*
  - Quarterly financial meetings w/BNL+PHENIX
  - Weekly reporting at PHENIX Planning meeting during final 3 years of project
- **PHENIX Managed Projects (HBD)**
  - Initial review by internal PHENIX committee
  - Weekly reporting at PHENIX Planning meeting during final 2 years of project

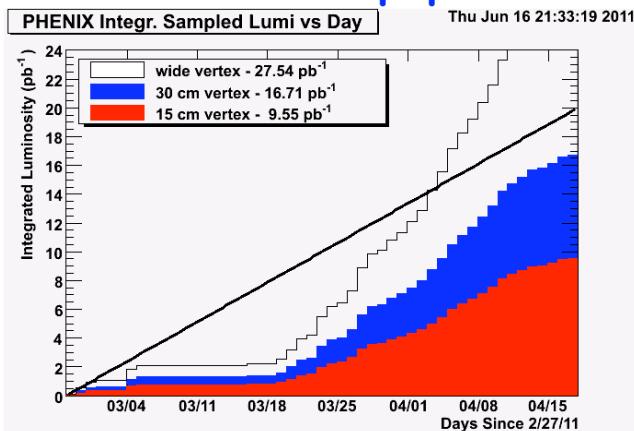


## Project Management, continued

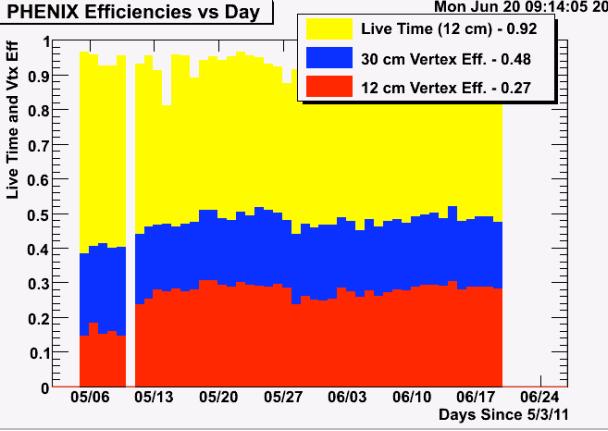
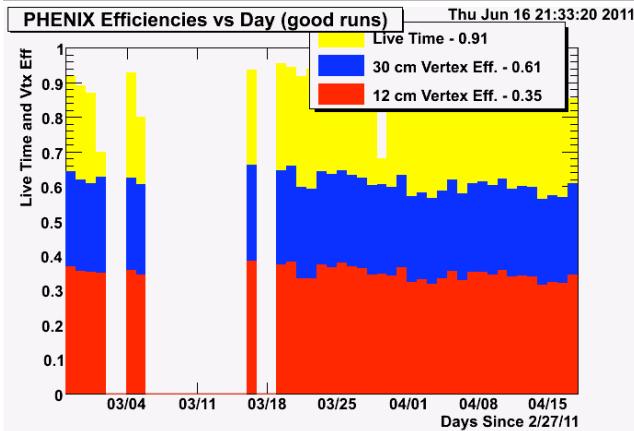
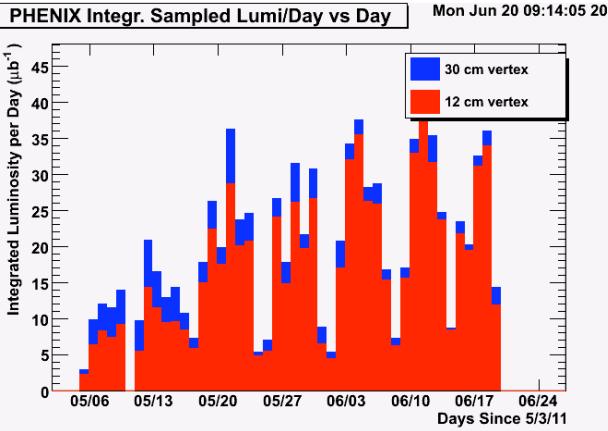
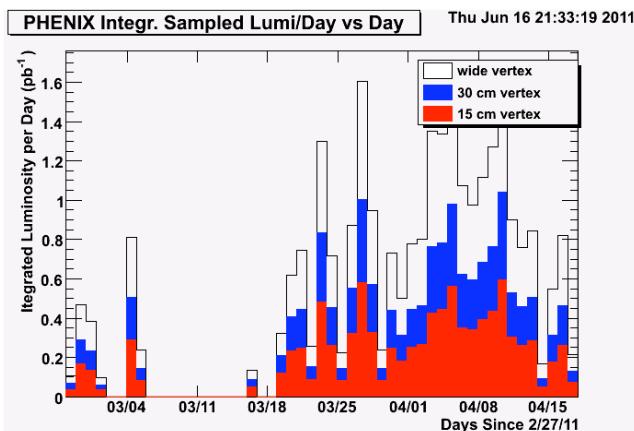
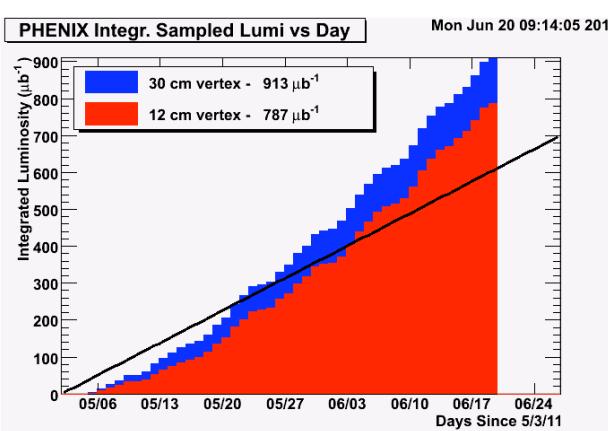
- All Upgrade detectors worked to spec (FVTX due for completion later in 2011)
- All Projects were at or below budget (VTX was under budget by \$140k)
- No upgrade missed its targeted RHIC Physics Run
  - HBD was ~ 1 year late. However, it was built with very new technology. HBD run successfully in Run-9 and 10.
  - MuTrg will be completed on schedule. Most MuTrg components ran successfully in Run-11. Final chambers being installed this summer.
  - VTX missed its project planned end date by 6-8 weeks but ran successfully in Run-11, as expected.
  - FVTX will be finished close to its original project end date. Expected to operate in RHIC Run-12.

## Data Taking in the High Rate Environment

**500 GeV p+p**



**200 GeV Au+Au**



**Run-11 Uptime:**

**200 GeV Au+Au: 71%**

**500 GeV p+p: 62%**

(not corrected for  
PHYSICS ON/OFF or  
for APEX days or  
Polarization  
measurements - i.e.  
just using ZDCNS to  
gauge if physics is ON)

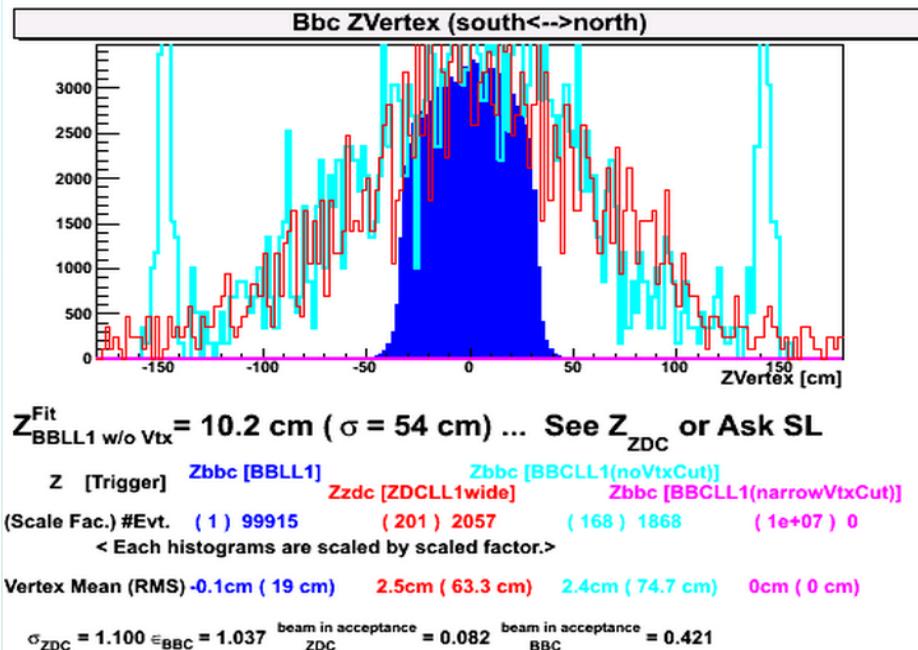
| PHENIX Efficiencies | 500 GeV p+p | 200 GeV Au+Au |
|---------------------|-------------|---------------|
| Livetime            | 91%         | 92%           |
| 30 cm vertex        | 61%         | 48%           |
| 12 cm vertex        | 35%         | 27%           |
| Uptime              | 62%         | 71%           |

# Vertex distribution

## BBC ONLINE MONITOR

## Run-10

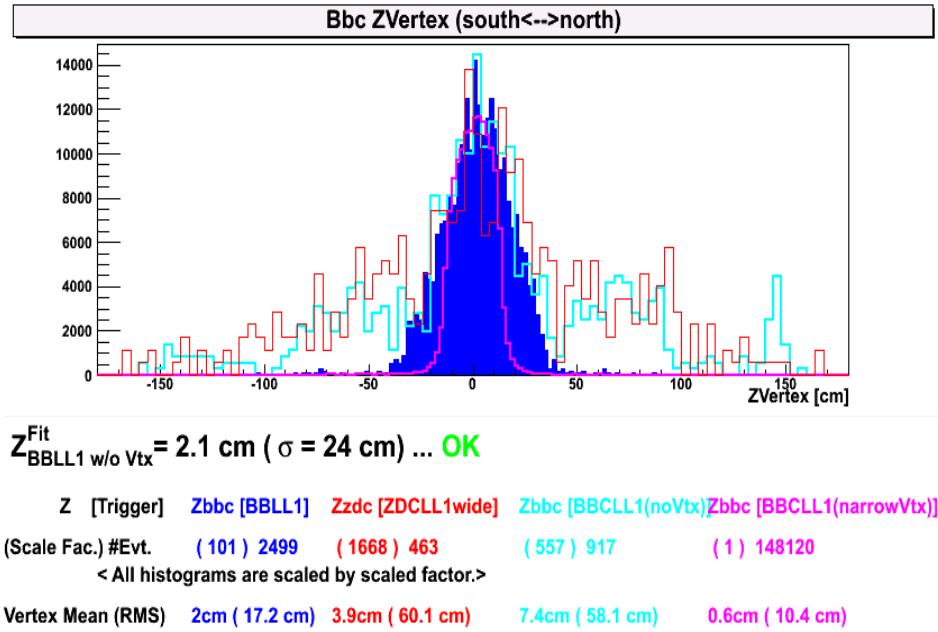
Run #300621 Events: 102730 Date:Mon Jan 11 05:52:19 2011



## BBC ONLINE MONITOR

## Run-11

Run #349676 Events: 150224 Date:Mon Jun 20 05:30:57 2011



- Stochastic cooling -> more collisions inside VTX acceptance  
Allows selectivity & rate with this modest sized detector  
Monitored by the shift crew
- For muon arm physics we use events in the full  $\pm 30 \text{ cm } Z_{\text{vx}}$



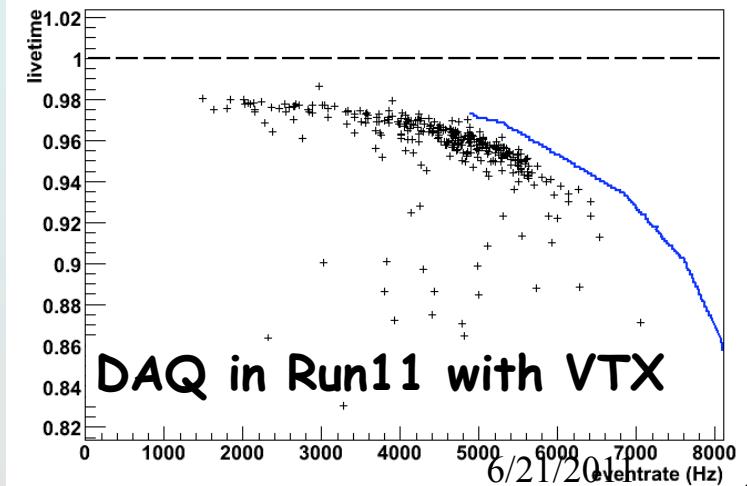
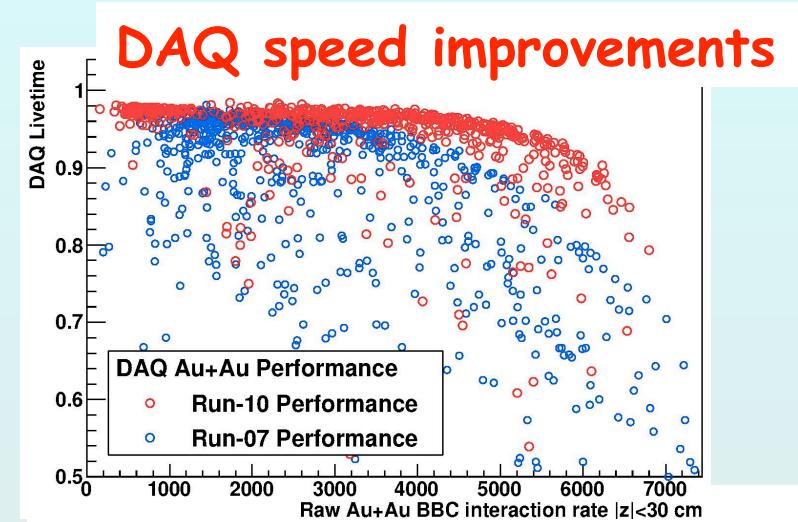
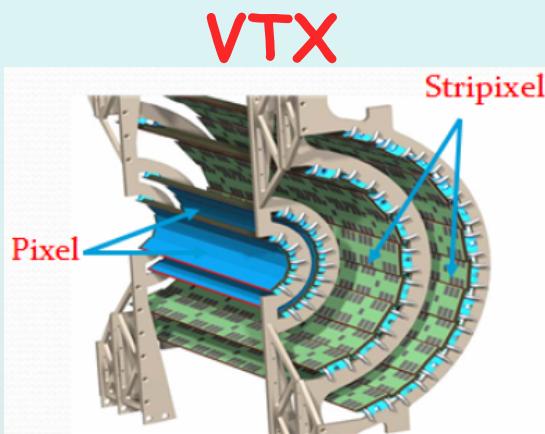
# DAQTrig2010 - High DAQ Speed With New Detectors

Fast front-end - DCM-II's & JSEB-II's

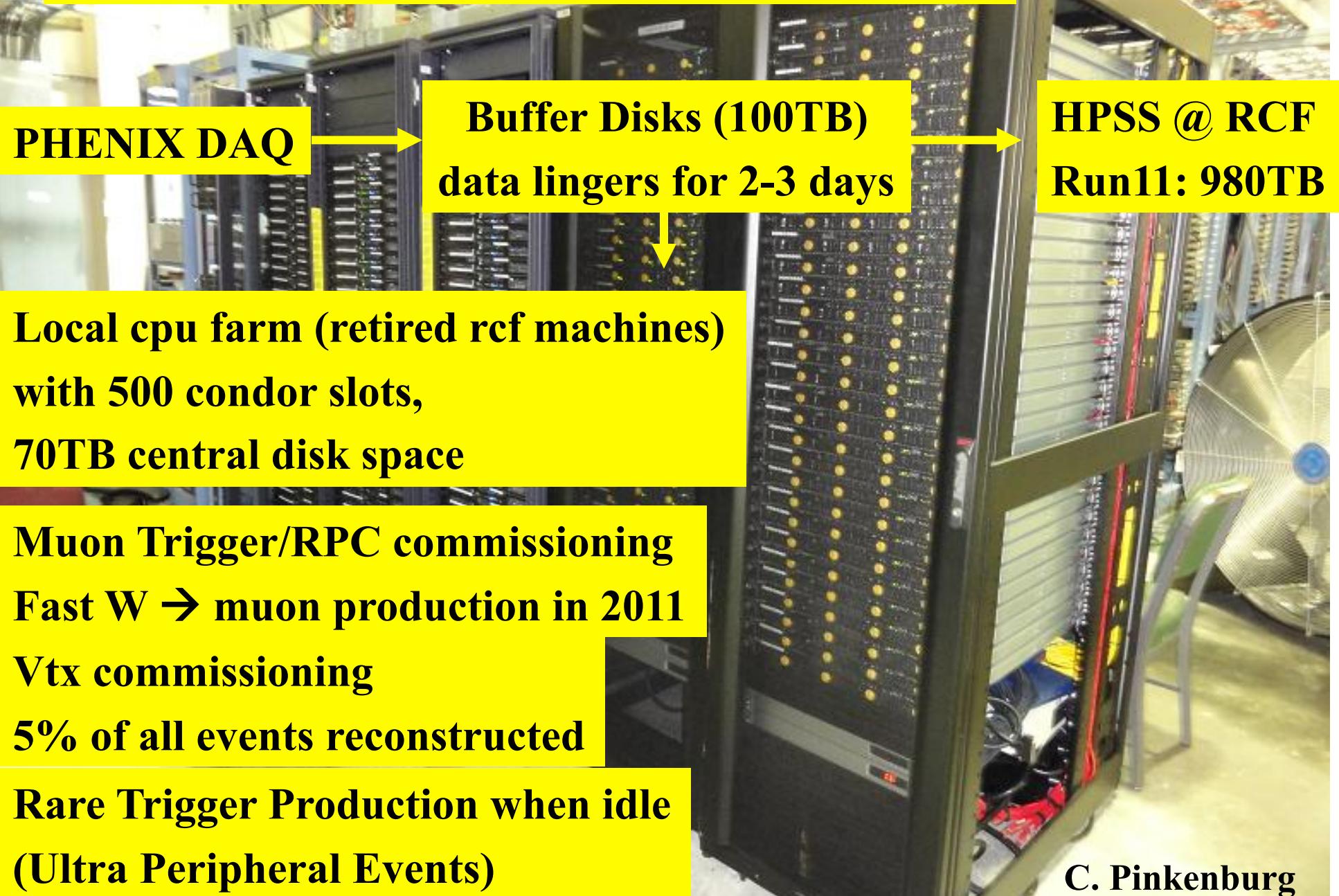
Heart of the Event Builder - new 10 Gbit Network Switch

Storage of the Data -

updates to the Buffer Boxes



*“Online” production: moving the CPU to the data*



C. Pinkenburg

# What does the future hold?

- PHENIX began asking this ~ 2 years ago  
Collaboration meetings & workshops; interest and enthusiasm
- Identify compelling new questions from RHIC discoveries  
Quantify the surprising properties of the QGP  
Some new “discovery” questions  
Revisit now that first LHC results are available  
Precision W, parton-spin correlations, possibly Drell-Yan ->  $\mu^+ \mu^-$
- Ask how best to answer these questions  
The PHENIX Experiment at RHIC  
New or improved capabilities, identify needed R&D  
Strategy for aging detector elements  
Developed a concept + evolution plan  
Modest initial scope, overall scope << a large new detector
- Wrote PHENIX Decadal Plan ~ one year ago  
Next: optimize evolution to ePHENIX



*start on first phase soon*



Spokesperson

Deputy Spokesperson

Deputy Spokesperson

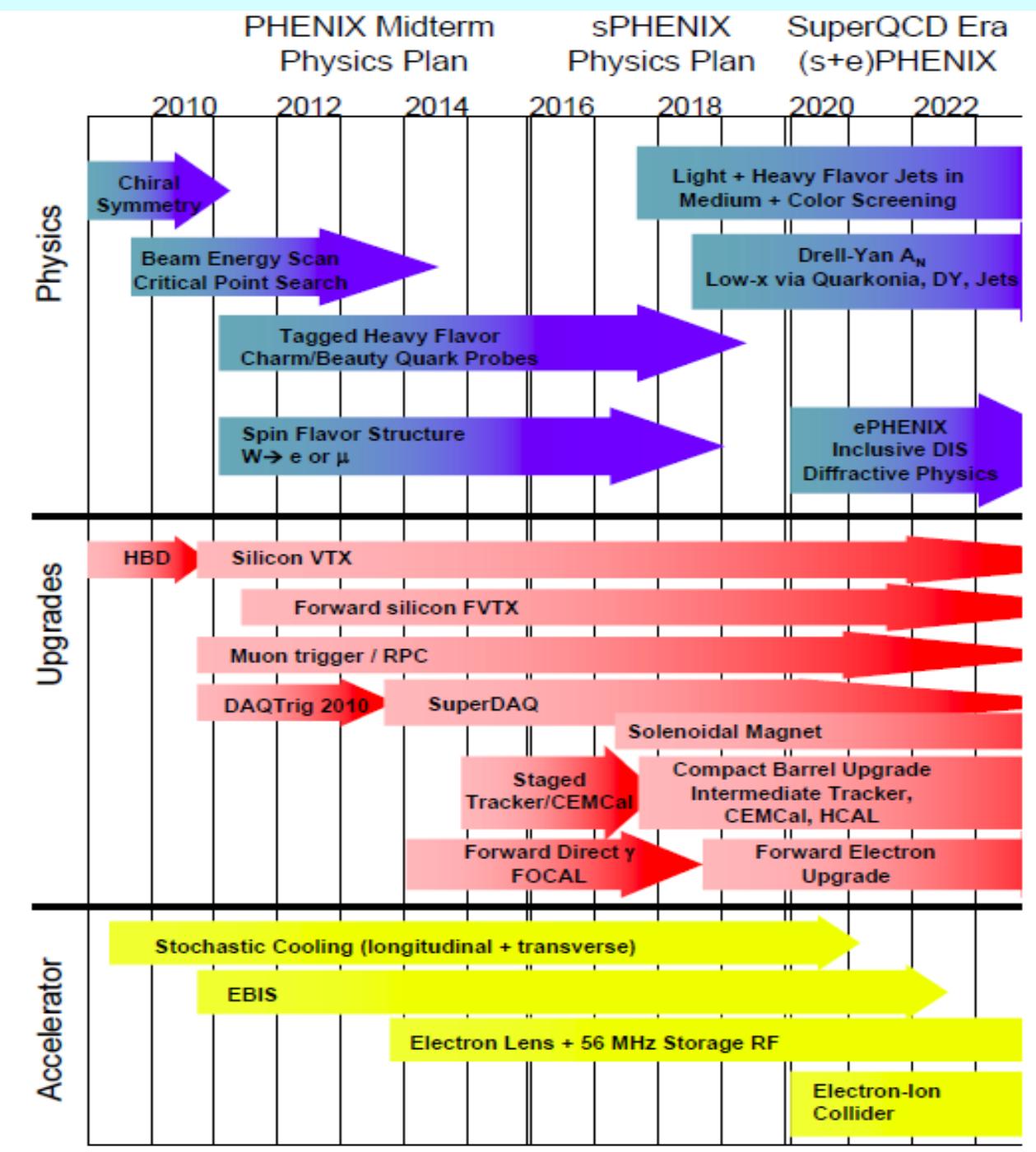
Operations Director

Barbara Jacak  
*Stony Brook University*  
Jamie Nagle  
*University of Colorado*  
Yasuyuki Akiba  
*RIKEN Nishina Center for Accelerator-Based Science*  
Ed O'Brien  
*Brookhaven National Laboratory*

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# Our big picture plan



# NEW questions due to RHIC discoveries

- Compelling goals for 2015+ - 2020
- Address with ion collisions

*Are quarks strongly coupled to the QGP at all scales?*

*Are there quasiparticles at any scale?*

*Mechanisms for parton-QGP interaction?  
and QGP response?*

*Is there a relevant screening length in the QGP?*

*How is rapid equilibration achieved?*

*What is the structure of cold nuclei at small-x?*

- Polarized proton running to answer

*Internal landscape of nucleons:* Spin? parton correlations

*Color Interactions in QCD*      Drell Yan, jets  $A_N$

*What governs hadronization?*

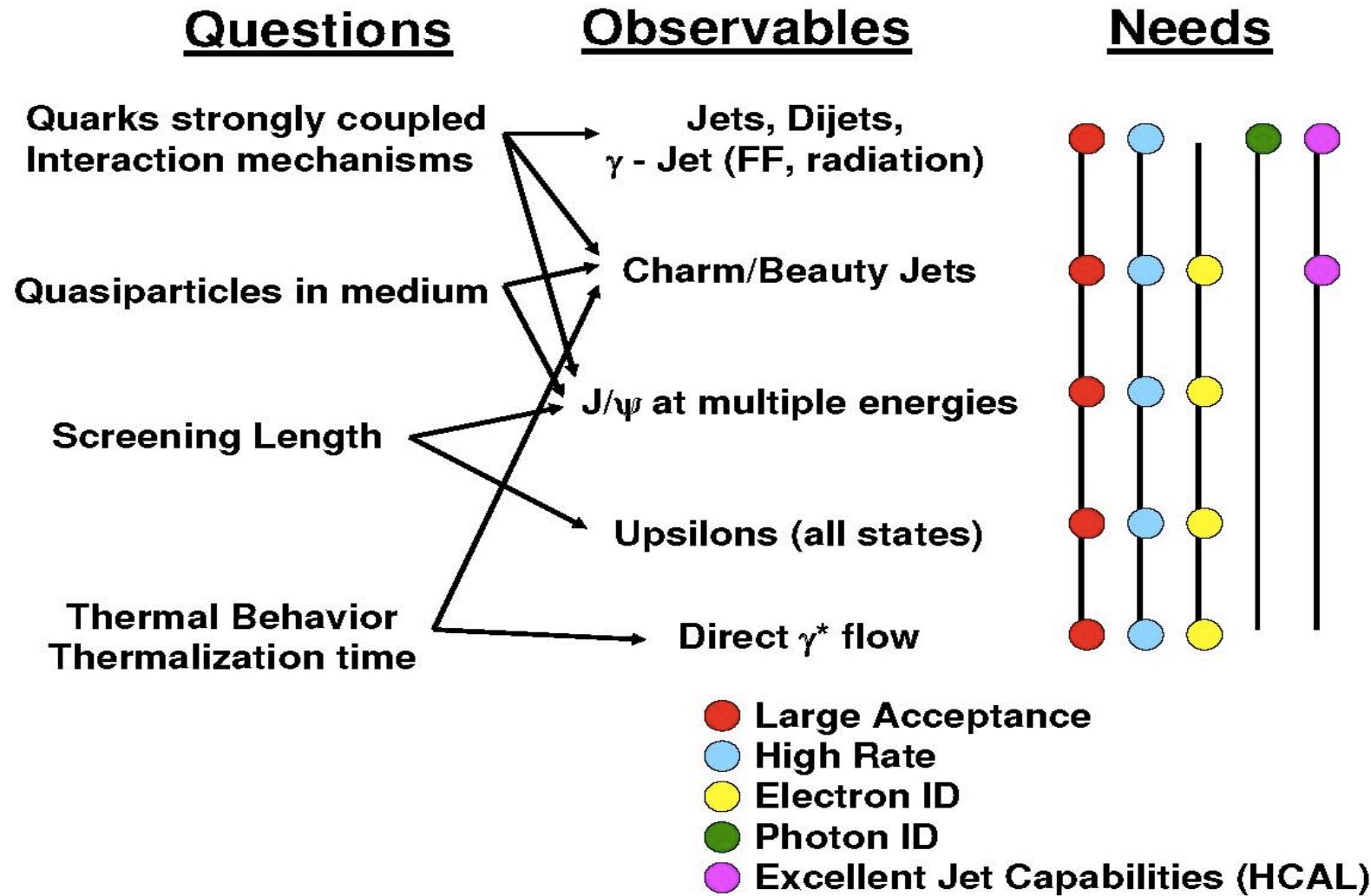


## Insights, given first LHC results

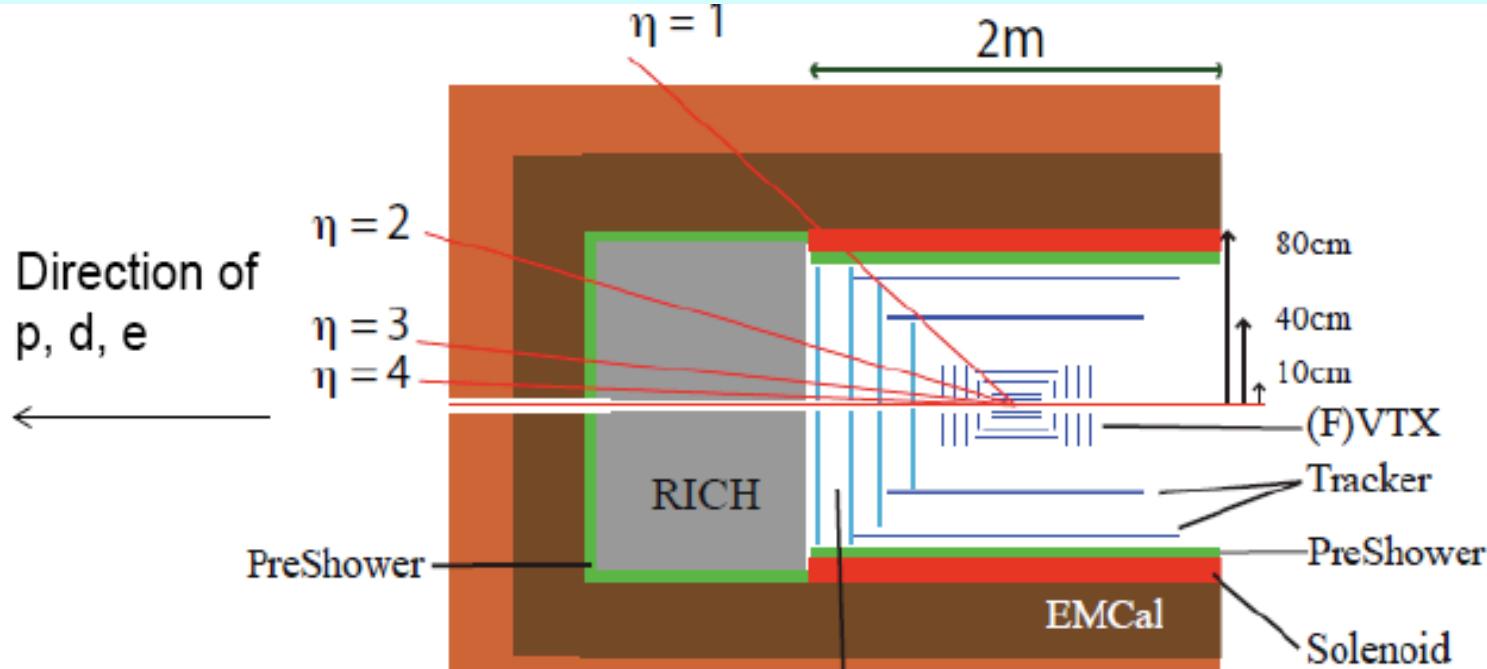
- Quarkonia energy dependence not understood!  
Need charmonium and bottomonium states at  $>1 \sqrt{s}$  at RHIC  
+ guidance from lattice QCD!
- Jet results from LHC very surprising!  
Steep path length dependence of energy loss  
also suggested by PHENIX high  $p_T v_2$ ; AdS/CFT is right?  
Little modification of jet fragmentation function  
looks different at RHIC  
Lost energy goes to low  $p_T$  particles at large angle  
is dissipation slower at RHIC? Due to medium or probe?  
Little modification of di-jet angular correlation  
appears to be similar at RHIC
- Need full, calorimetric reconstruction of jets in wide  $y$  range at RHIC to disentangle probe effects/medium effects/initial state



# To answer these questions



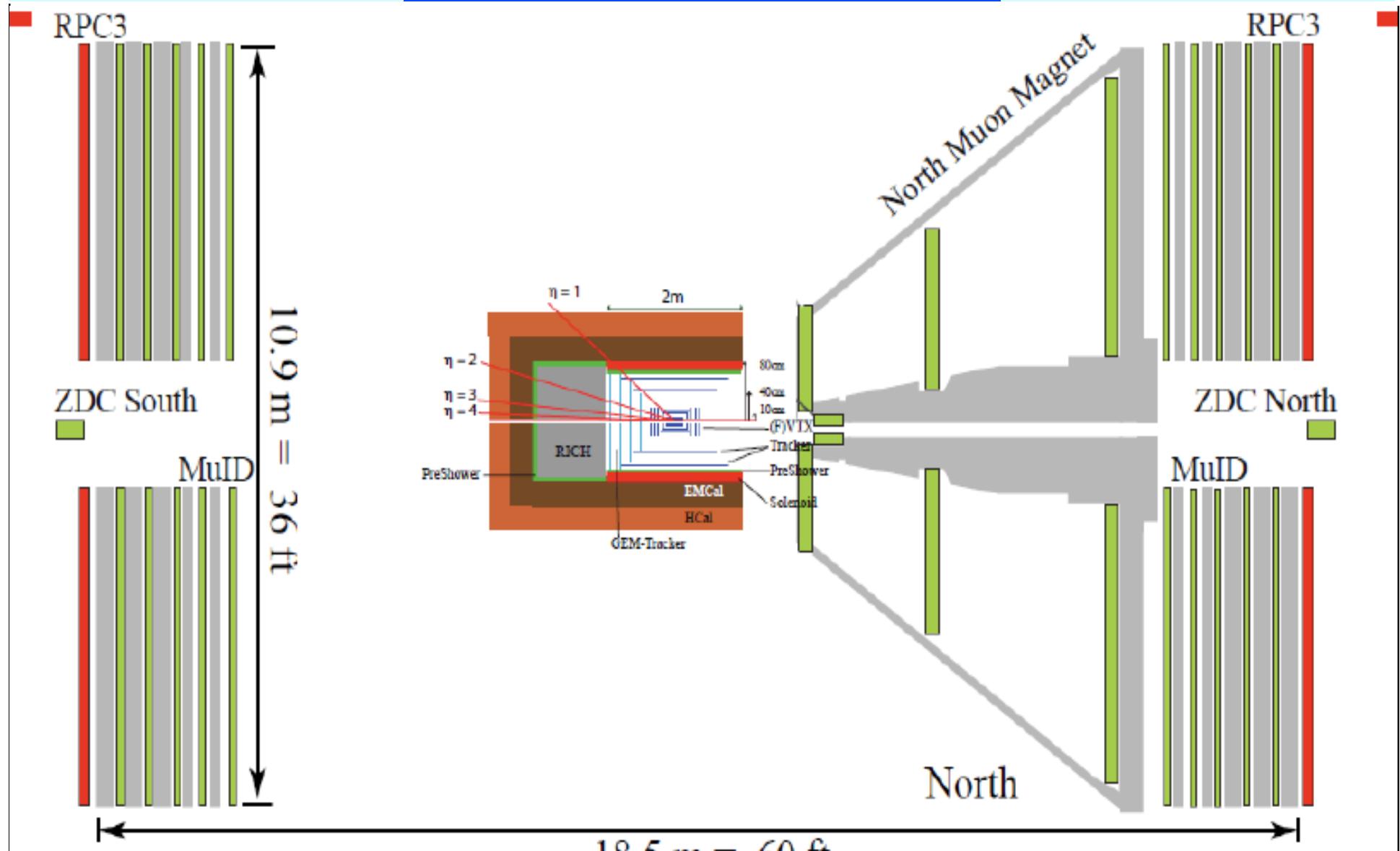
## Upgrade Concept



*Focused on capabilities to answer compelling questions  
Don't try to do everything*

- Compact detector covering  $-1 < \eta < 4$
- Measure jets, electrons and photons in mid-rapidity → Measure QGP properties
- Gluon saturation physics at forward region ( $\eta > 1$ )
- First eRHIC detector (not yet optimized)

# How does this happen?



# Cost estimate

## Carry over from existing PHENIX:

- VTX and FVTX
- EMCal in Forward Arm and perhaps barrel
- DAQ
- Infrastructure (LV, HV, Safety systems...)

## What is new:

- 2-3T solenoid ( $R = 60-100$  cm)
- Preshower detector
- Barrel EMCal (maybe new)
- Hadronic Calorimetry
- Additional tracking layers of Si at  $\sim 40$ cm
- Forward Arm with RICH and GEM tracker

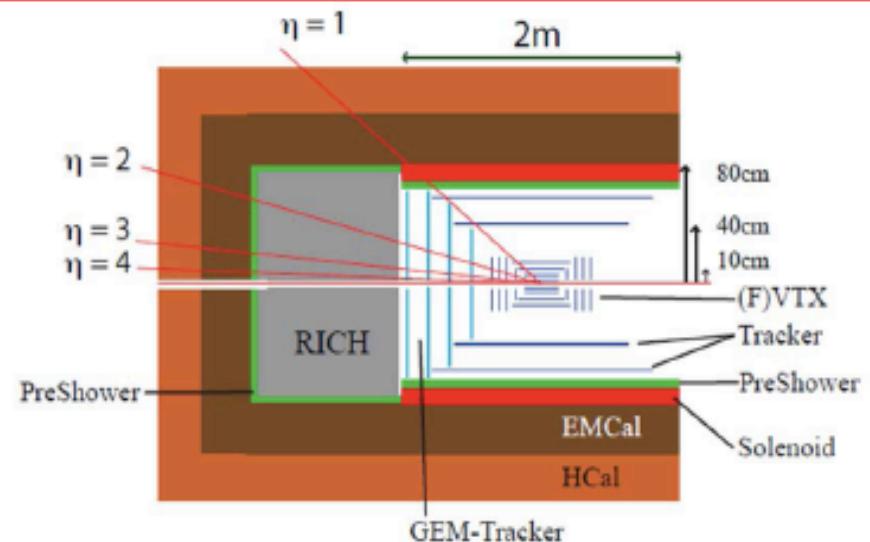
} \$20M  
} \$8-10M  
} \$5-7M  
} \$10M

### Other

- Forward magnet
- Forward HCAL
- Barrel tracking layer  $\sim 60$ cm

} \$10-15M

*All cost estimate include overhead and contingency*



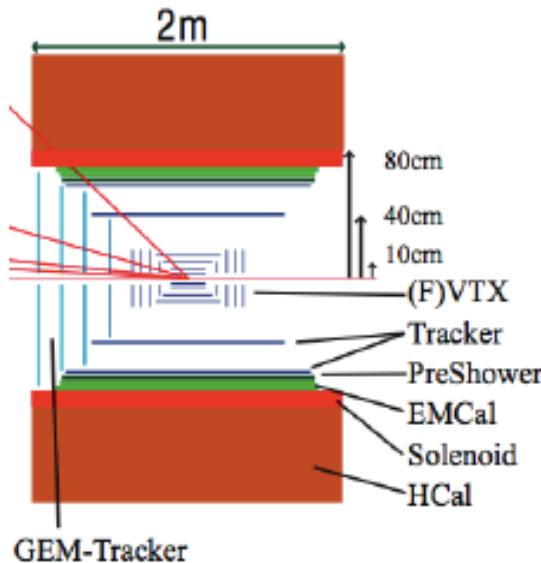
*Can be built incrementally*

**Total Project Cost \$53-62M**

- Approx ½ replacement cost of existing \$130M PHENIX detector
- DOE contribution estimated to be 60% of total \$32-44M
- Forward detector is key for eRHIC physics (part of eRHIC project?)



# Staging



- Mid-rapidity detector
- Additional (Si)tracking
- Solenoid
- pre-shower
- EMCal
- Hcal

*High stat. charm*

5-7 M

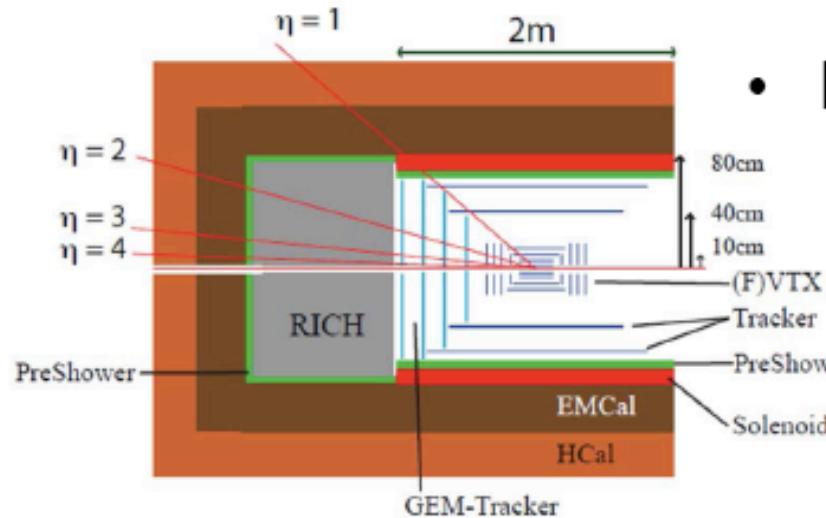
*Direct  $\gamma, \pi^0$*

*Quarkonia*

20 M

*Jets*

8-10M



- Forward Detector
- RICH and GEM tracker
- Forward magnet
- Forward Hcal
- More barrel tracker

*CNMs,  
eRHIC*

10M

*Saturation*

*QGP @ Fwd  
eRHIC*

10-15M

## Issues and Concerns

- RHIC performance for 500 GeV polarized p+p
  - Not up to the usual RHIC standards
  - We only got  $\int L dt = 18 \text{ pb}^{-1}$  within our vertex cut of 30cm
  - Polarization was  $\sim 50\%$
  - 300  $\text{pb}^{-1}$  in 30 cm is necessary for impactful measurement!
  - We need  $\geq 55\%$  polarization AND high luminosity to do the job
- Can this program be completed in 2 years?
  - NSAC milestone HP8 is set for 2013
  - If we do not reach in 2 years, will need more pp running...
- Staffing is an ever tougher issue
  - It is necessary to add new detectors
  - Supporting them requires technical staff
    - University groups funded only for postdocs & students
    - BNL staff is  $\sim$  constant



big issue now: replace the Computing Coordinator

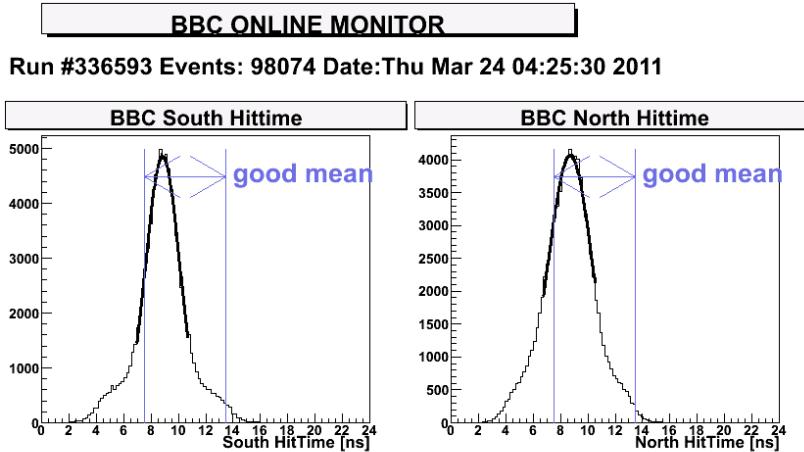
56



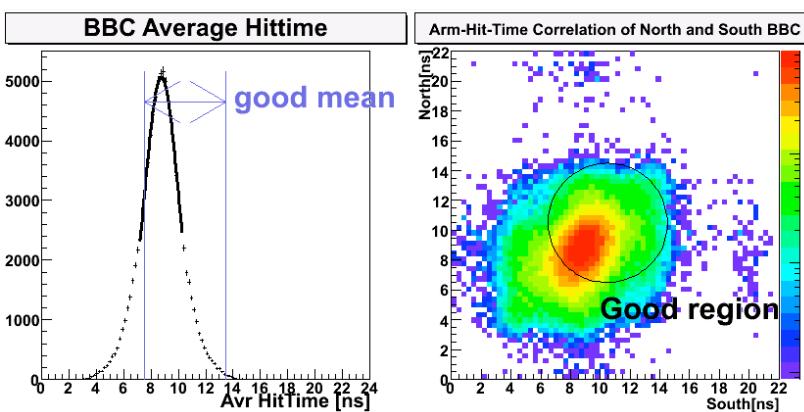
- backup slides

# Vertex Distributions: p+p and Au+Au

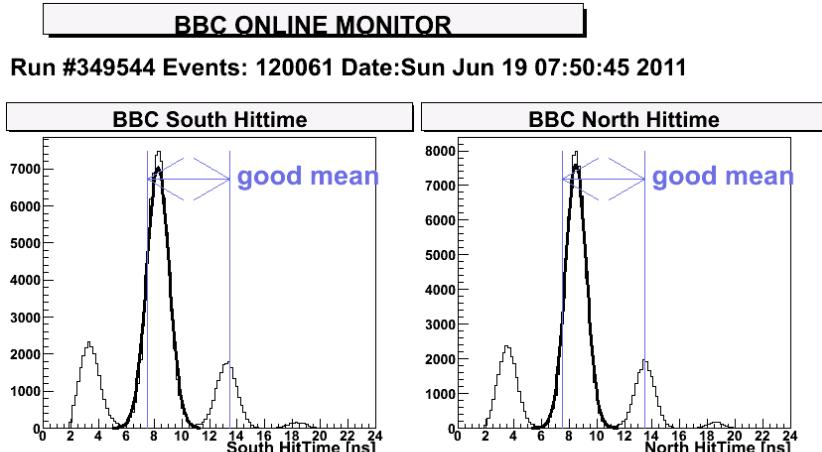
**500 GeV p+p**



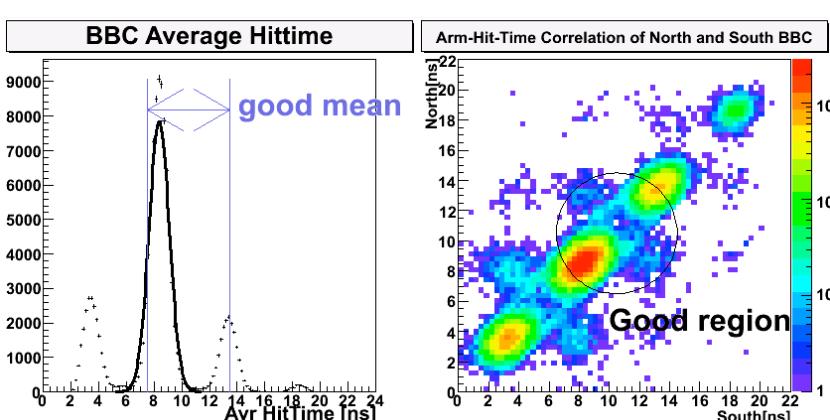
South:8.8[ns] North:8.7[ns] ... **OK**  
 Global offset : **OK**  
 Shown data are triggered by BBLL1  $|z|<130\text{cm}$



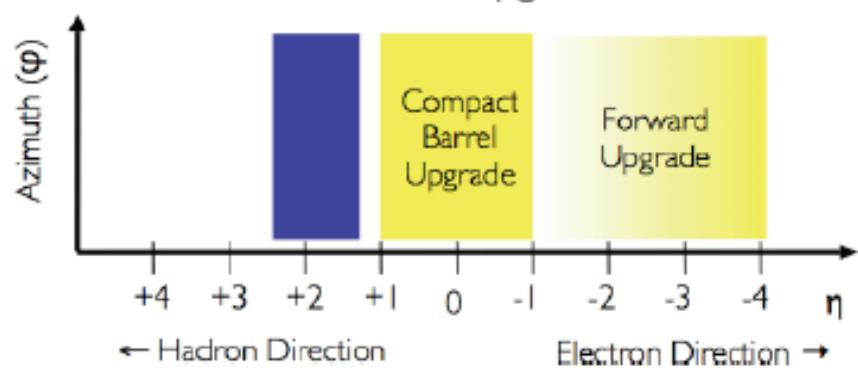
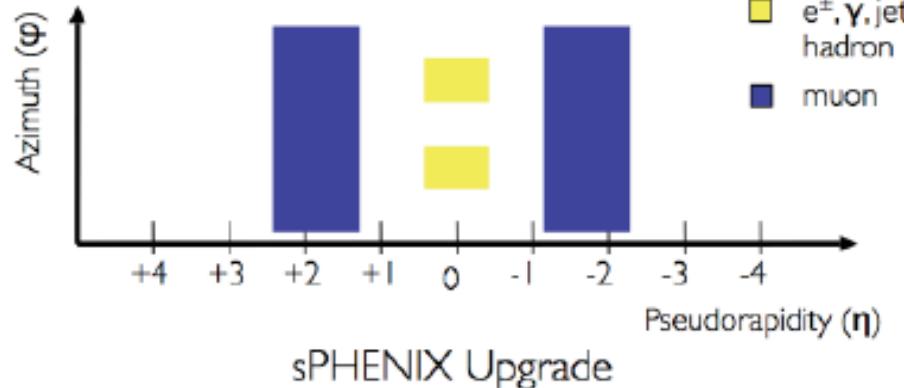
**200 GeV Au+Au**



South:8.2[ns] North:8.4[ns] ... **OK**  
 Global offset : **OK**  
 Shown data are triggered by BBLL1  $|z|<130\text{cm}$



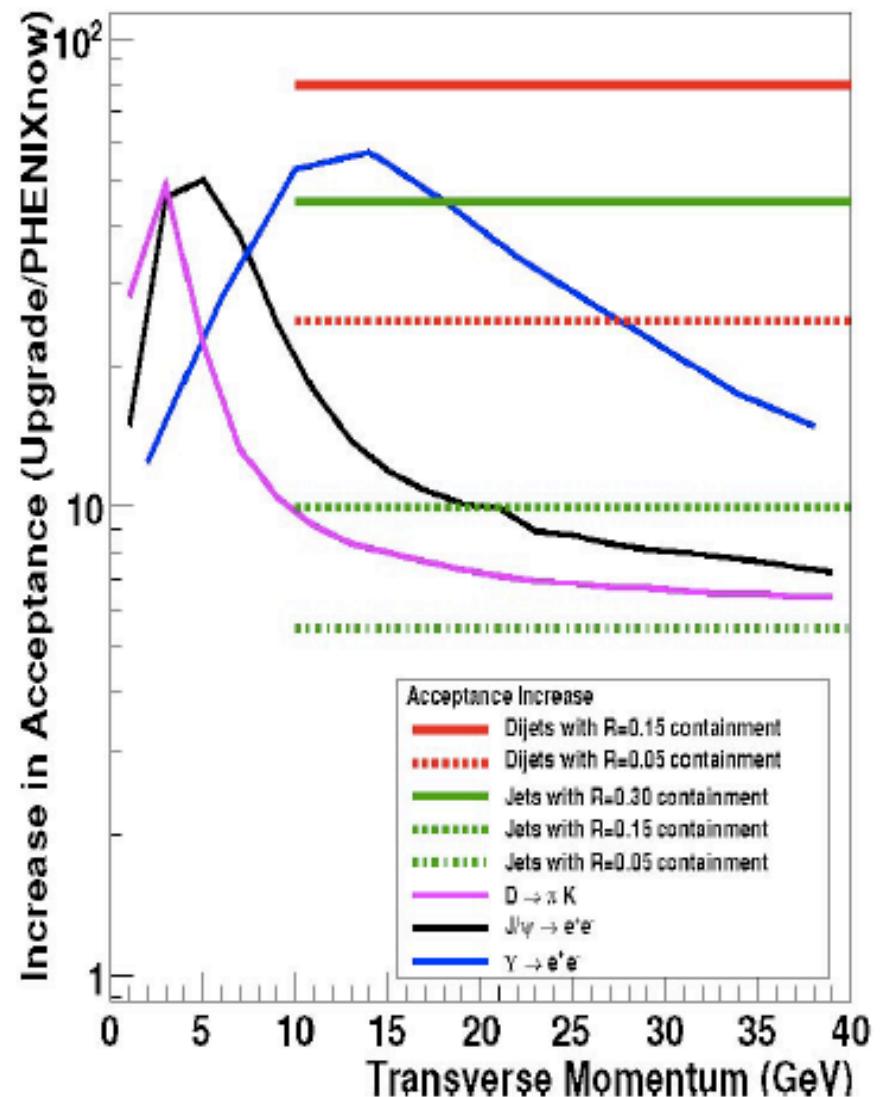
# sPHENIX acceptance



+ DAQ/Trigger: 50B events / year!

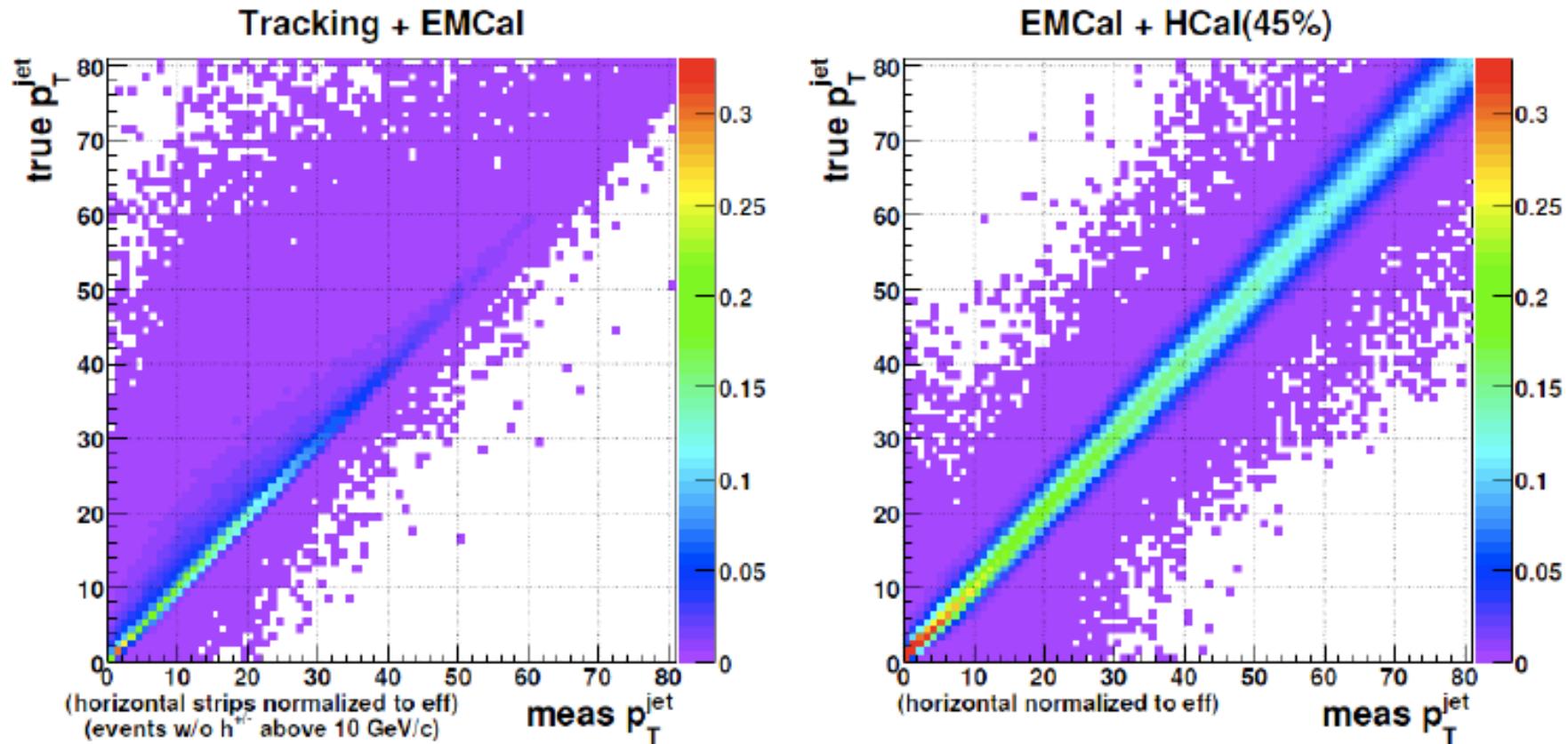
28

Much larger acceptance than PHENIX



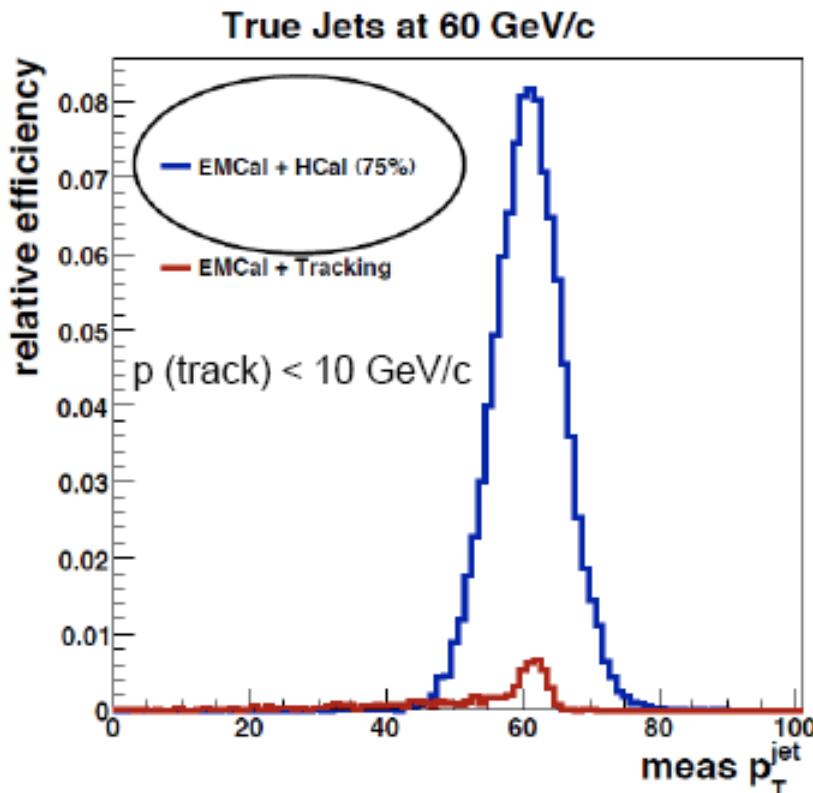
# HCal improvement to Jet Energy Measurement

tracking  $p < 10 \text{ GeV}/c$  required  
to avoid fake jets

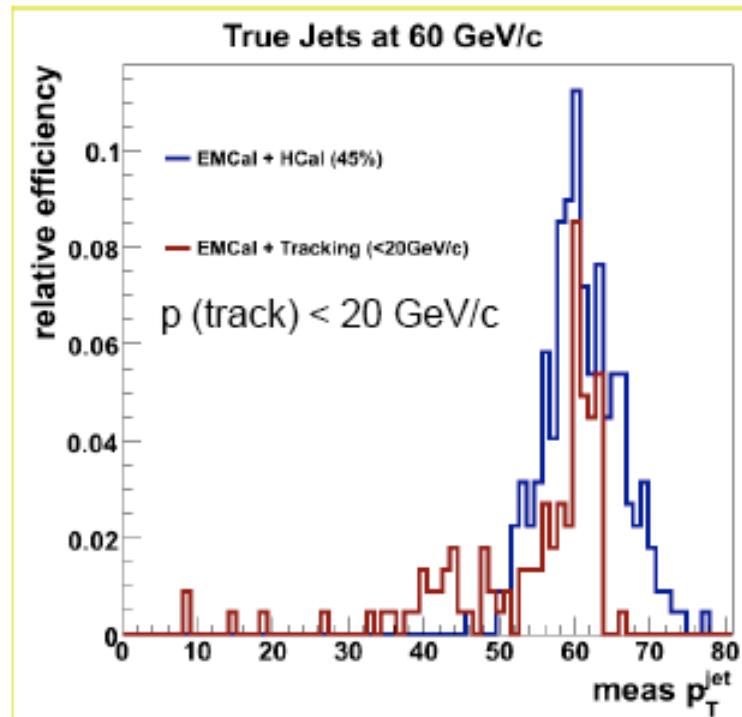


- No fake jet due to tracking background
- Catch neutral energy
- No asymmetric tail in measured energy → Essential for  $A_J$  measurement

# HCal for jet measurement



With 10 GeV tracking cut off, only tiny fraction of jet can be reconstructed



With 20 GeV tracking cut off, still less than 1/3 of jet is reconstructed at proper energy

- For di-jet asymmetry ( $A_J$ ) measurement, the tail is the killer
- Hcal eliminates the tail.
- Hcal is not the cost driver of sPHENIX

# Beam Energy Scan

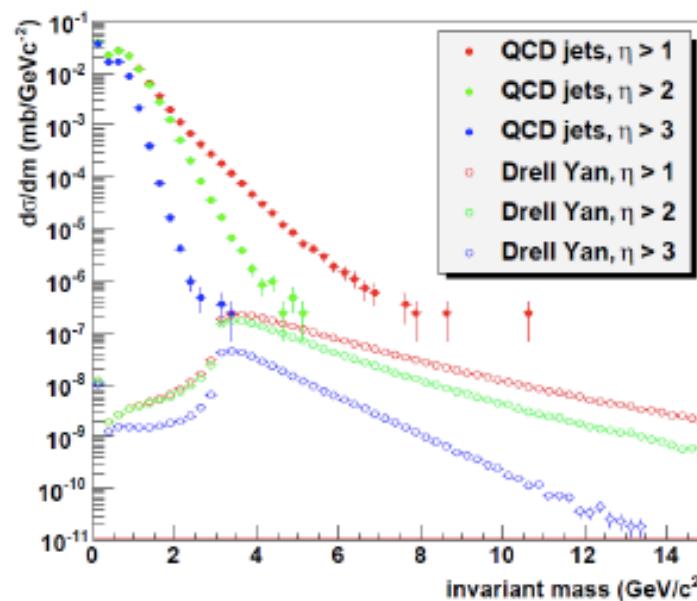
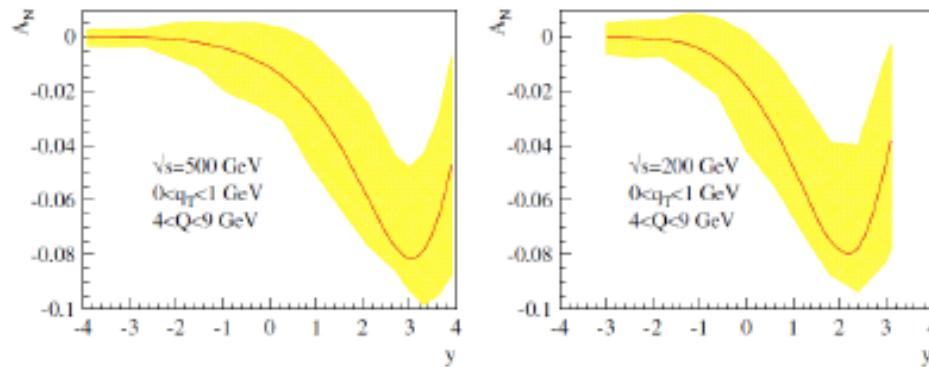
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Large acceptance → Energy scan of rare probes at lower beam energy

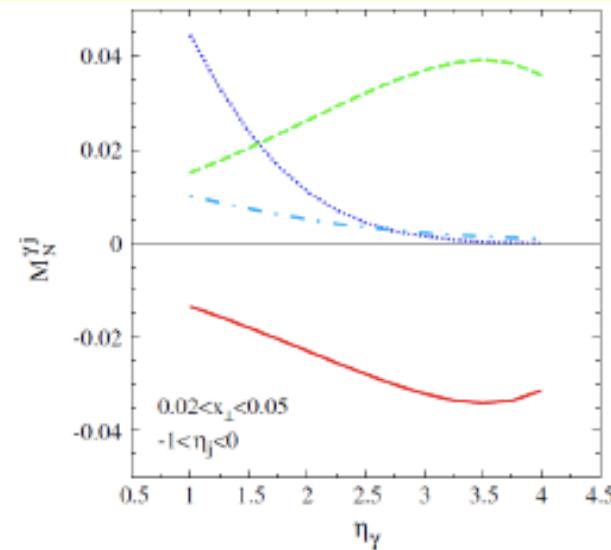
- Jets
- High  $p_T$  single hadrons
- Open heavy flavor
- Quarkonia
  - repeat energy scan of 20 – 200 GeV with large acceptance detector to characterize the suppression as a function of  $\sqrt{s}$
- Photon-hadron, Photon-jets
  - Probe Energy loss and QGP response in lower beam energy

# Spin Physics with sPHENIX

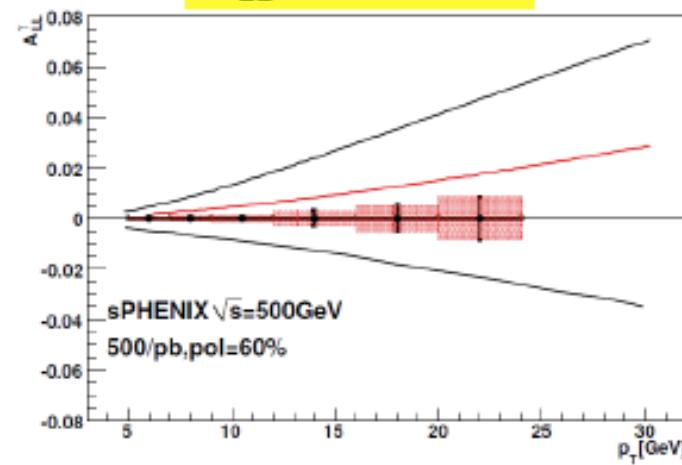
$A_N$  of DY at forward rapidity



$\gamma$ -jet transverse spin moment



$A_{LL}$  of Direct  $\gamma$



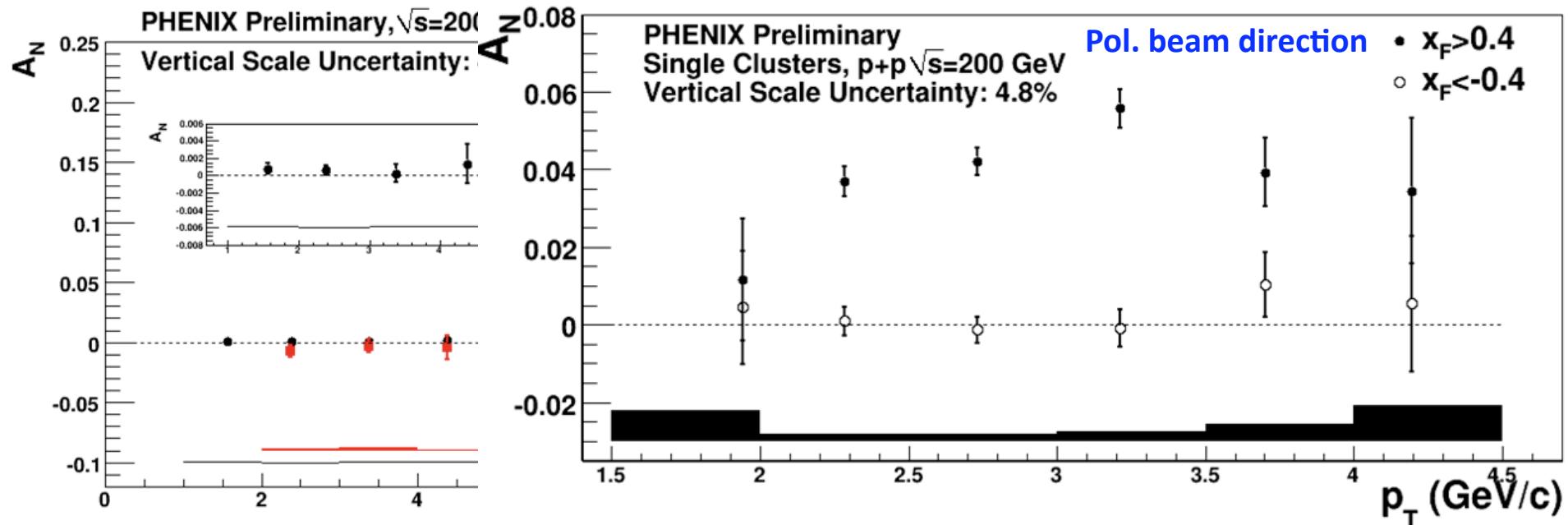
## Transverse single spin asymmetries

- $A_N \sim 0$  at mid-y, large at forward rapidity. Why??

Initial state correlations between  $k_T$  & p spin? (Sivers)

Spin dependent fragmentation functions? (Transversity x Collins)

Effects at sub-leading twist? (Qiu, Sterman)



- Past measurements statistics limited → more 200 GeV data!

NSAC milestone HP13 (sign change in Sivers asymm. in DY)  
requires 125 pb<sup>-1</sup> in PHENIX



## Forward physics upgrade

- Transverse spin phenomena

- Reach high  $x_F$  at  $|\eta| > 2$

- Drell-Yan: test QCD prediction SIDIS vs. Drell-Yan

- Separate Sivers and Collins; do flavor separated PDFs

- Longitudinal spin phenomena

- Extend x coverage for  $\Delta G$  and  $\Delta q$

- Drell-Yan in d+Au

- Quark distributions in nuclei

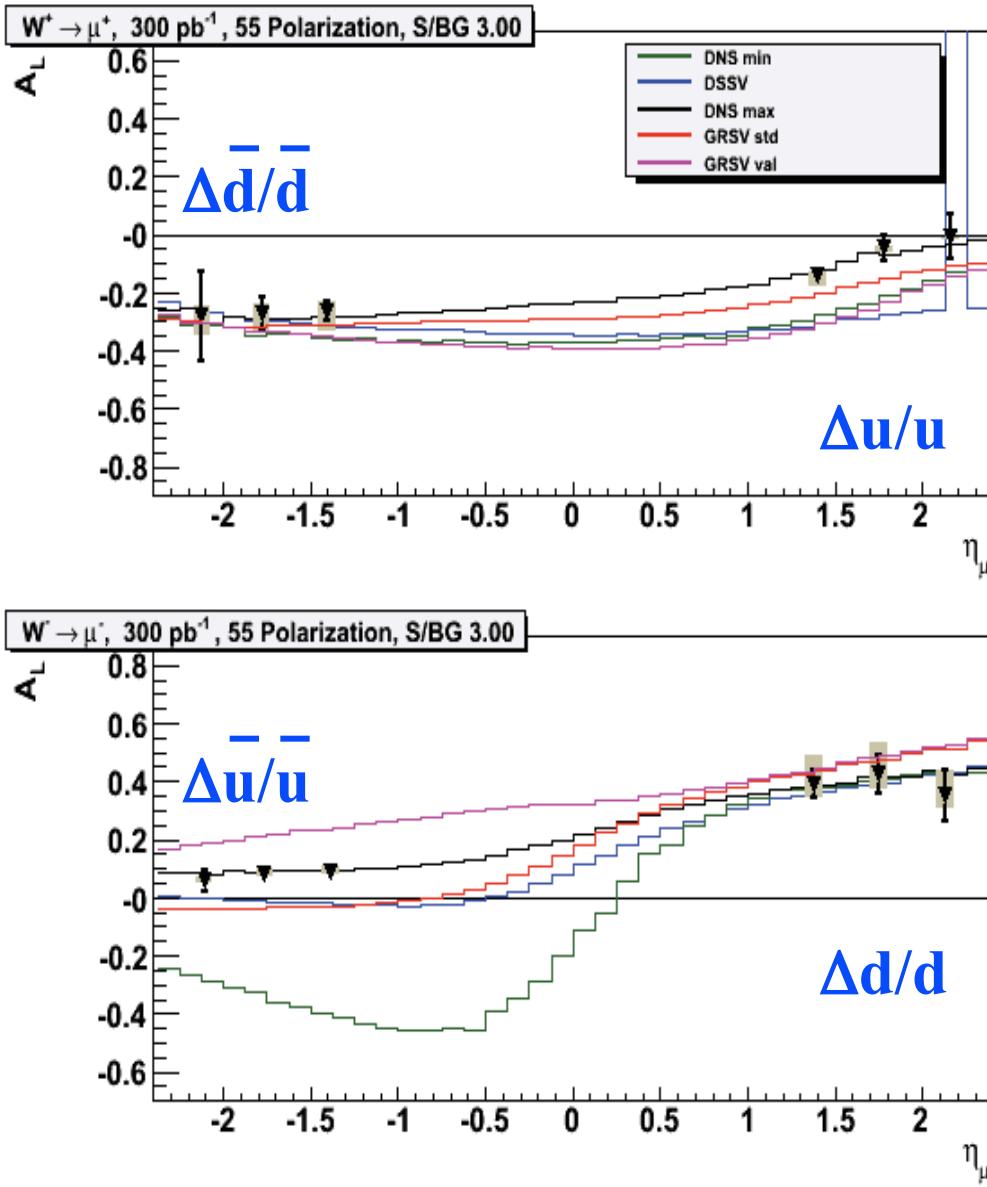
- First EIC physics

- Polarized and unpolarized inclusive structure functions

- in ep and eA ( $F_2, F_L, F_3, g_1, g_2, g_5$ )

- DVCS + other diffractive processes?

# Run-12 top priority: progress on W program

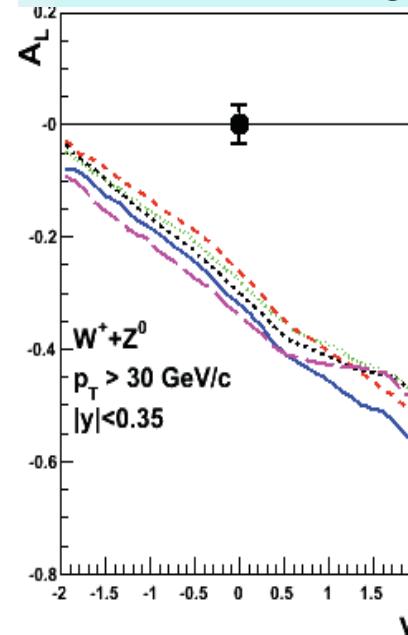


inclusive high  $p_T$  leptons

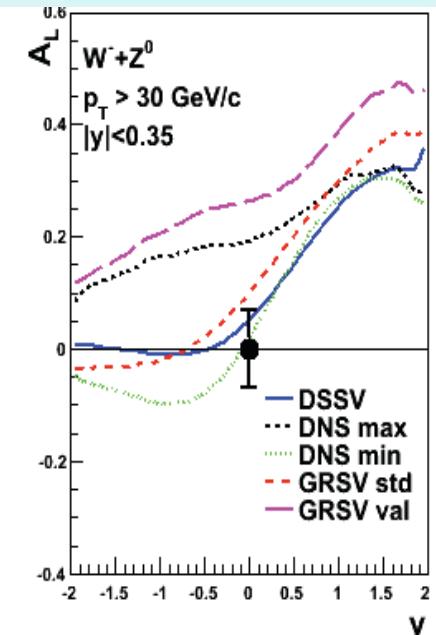
$\int L dt = 300 \text{ pb}^{-1}$  in 30cm,  $P=0.55$

Run-12 (100pb $^{-1}$ ) + Run-13

$W^+ \rightarrow e^+ + \nu_e$

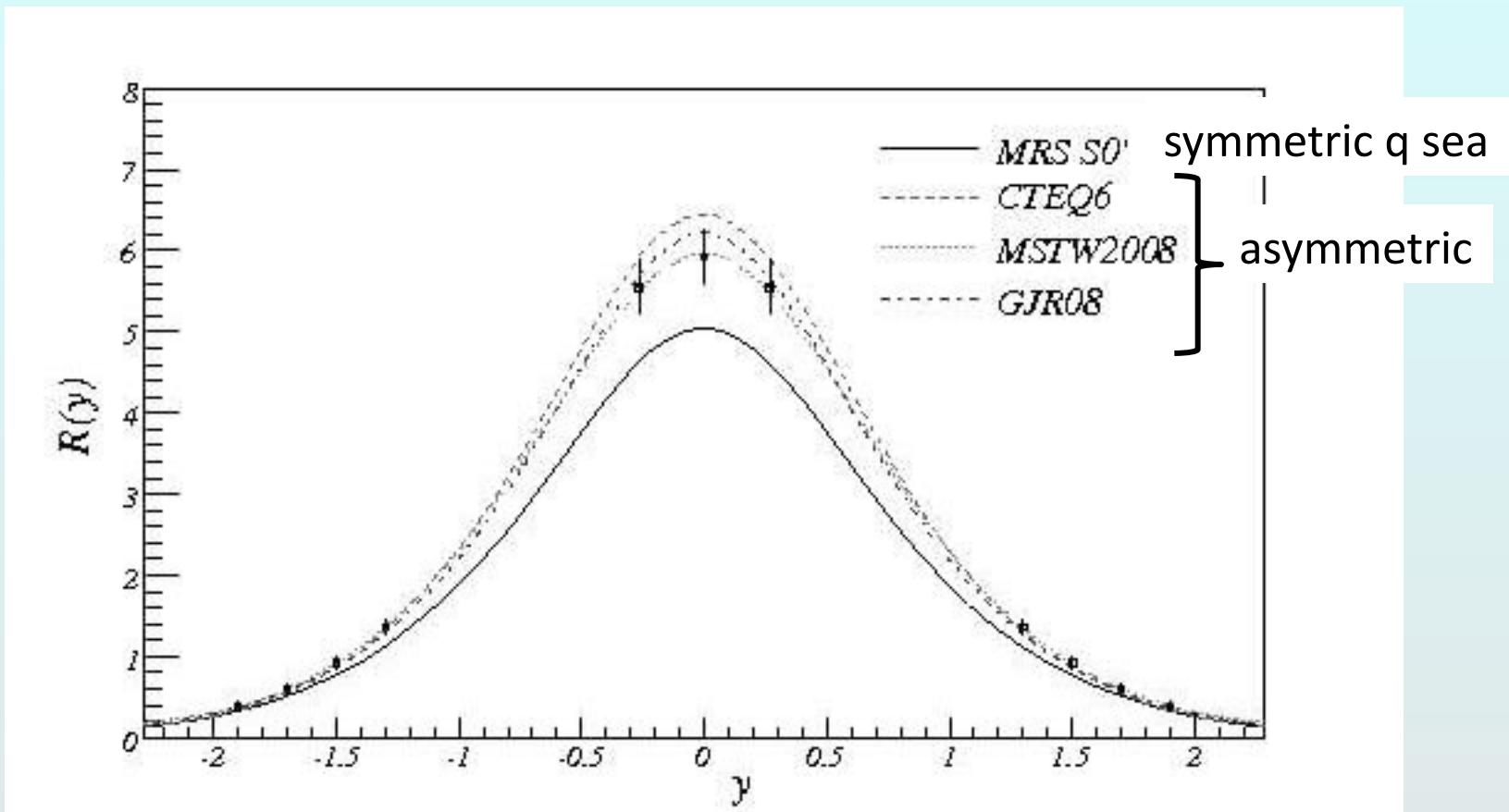


$W^- \rightarrow e^- + \bar{\nu}_e$

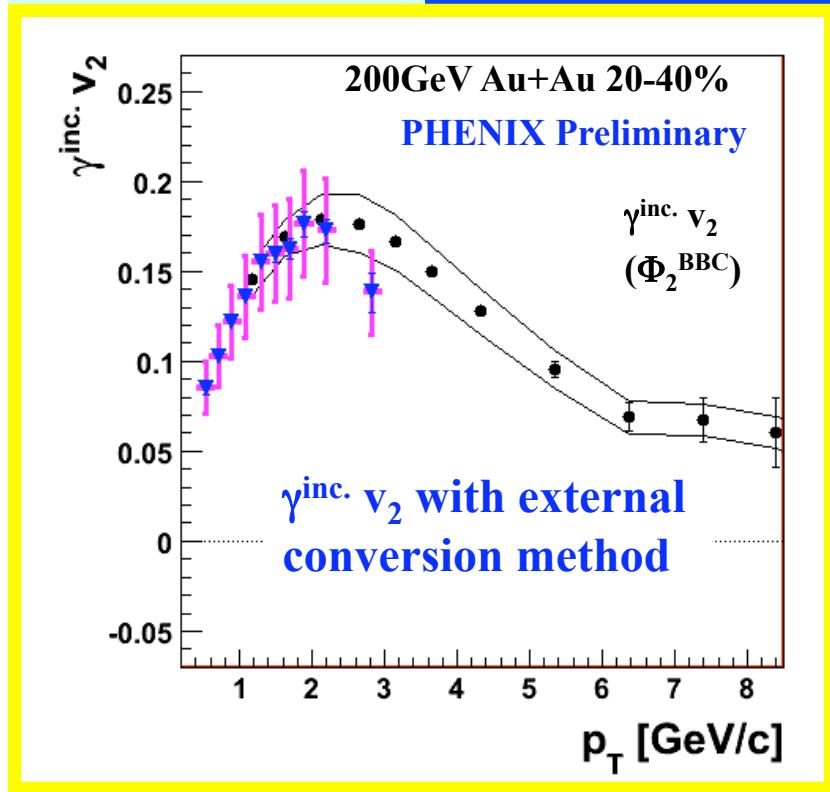


Requires  $\int L dt = 900 \text{ pb}^{-1}$   
delivered in Run-12+13

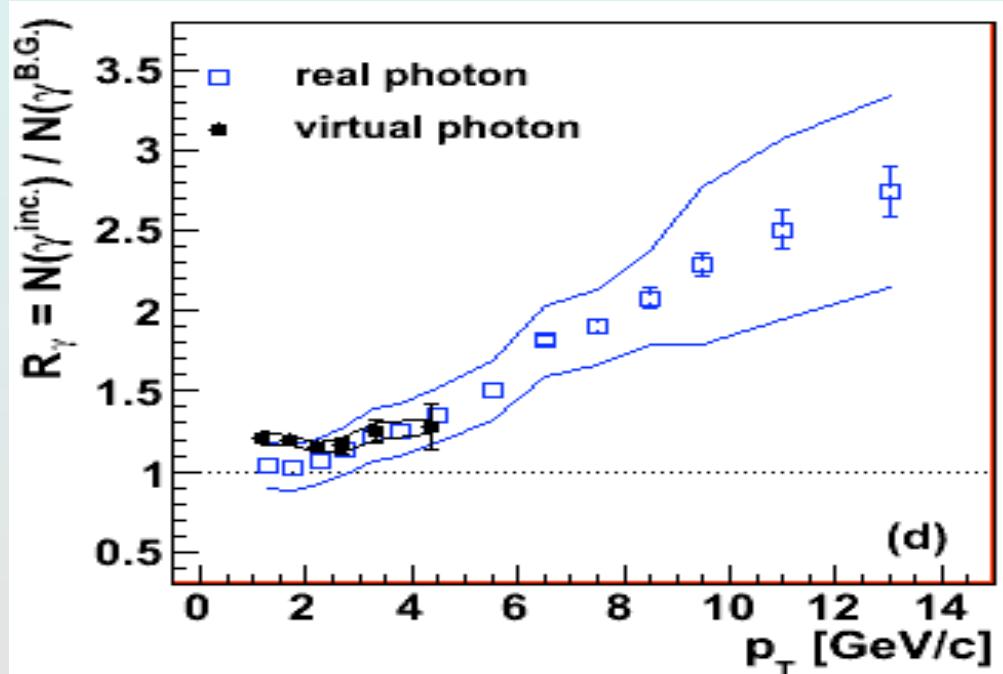
## Constrain dbar/ubar with W+/W- ratio



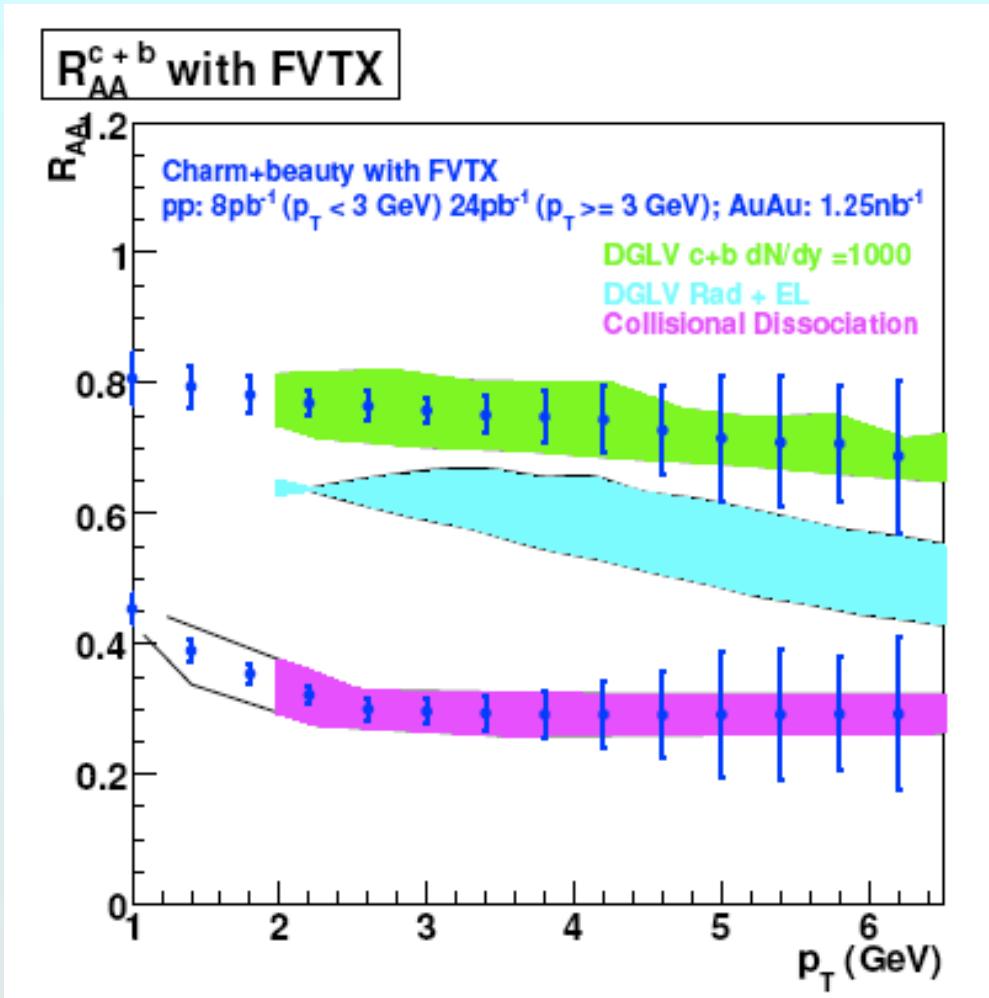
# Direct photon flow ingredients



- Key cross checks:
  - $\gamma^{\text{inc}}$  are really  $\gamma$ 's:  
check using  $\gamma \rightarrow e^+e^-$
  - $R_\gamma$  for virtual vs. real  $\gamma$



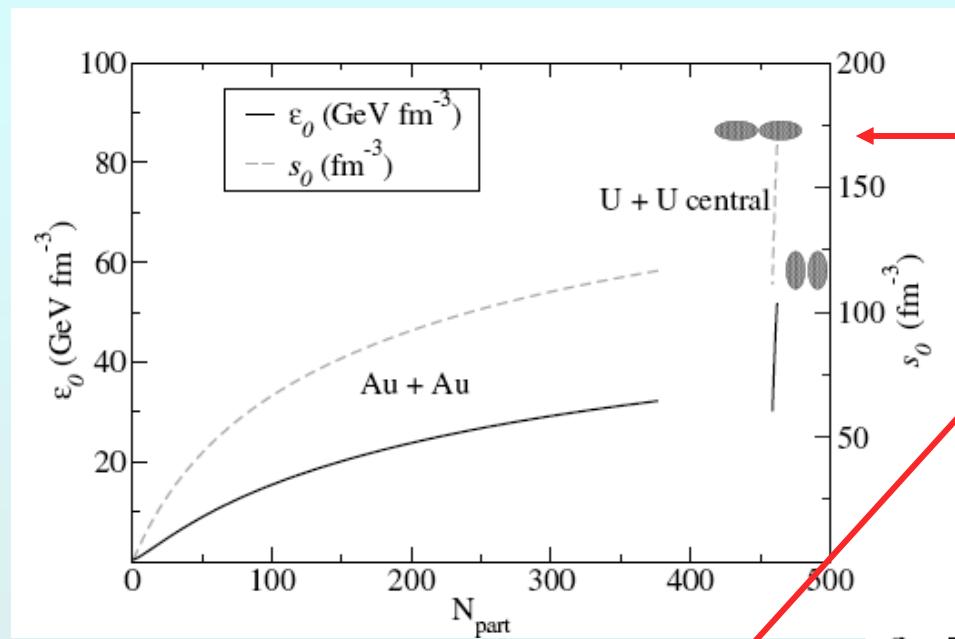
# Run-12 FVTX physics



## Run-12 Goals:

- Commission
- Collect first part of the data set at left
- ~1/6 of 4.6 nb<sup>-1</sup> minbias
- One run already has discriminating power for energy loss models

# U+U

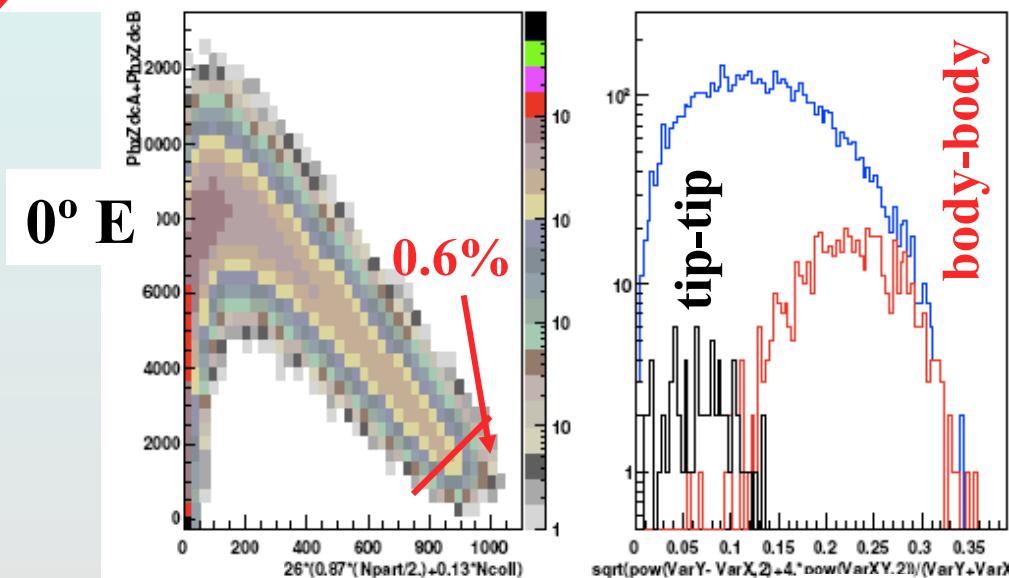
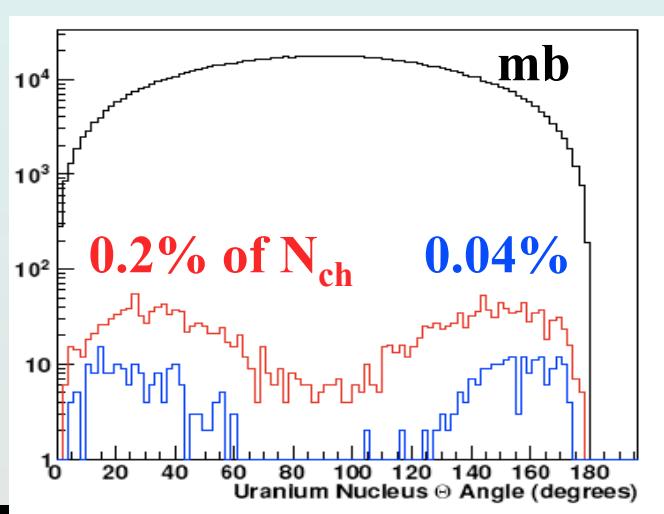


*Glauber MC simulations show:*

Goal: vary  $\epsilon_0$ , eccentricity

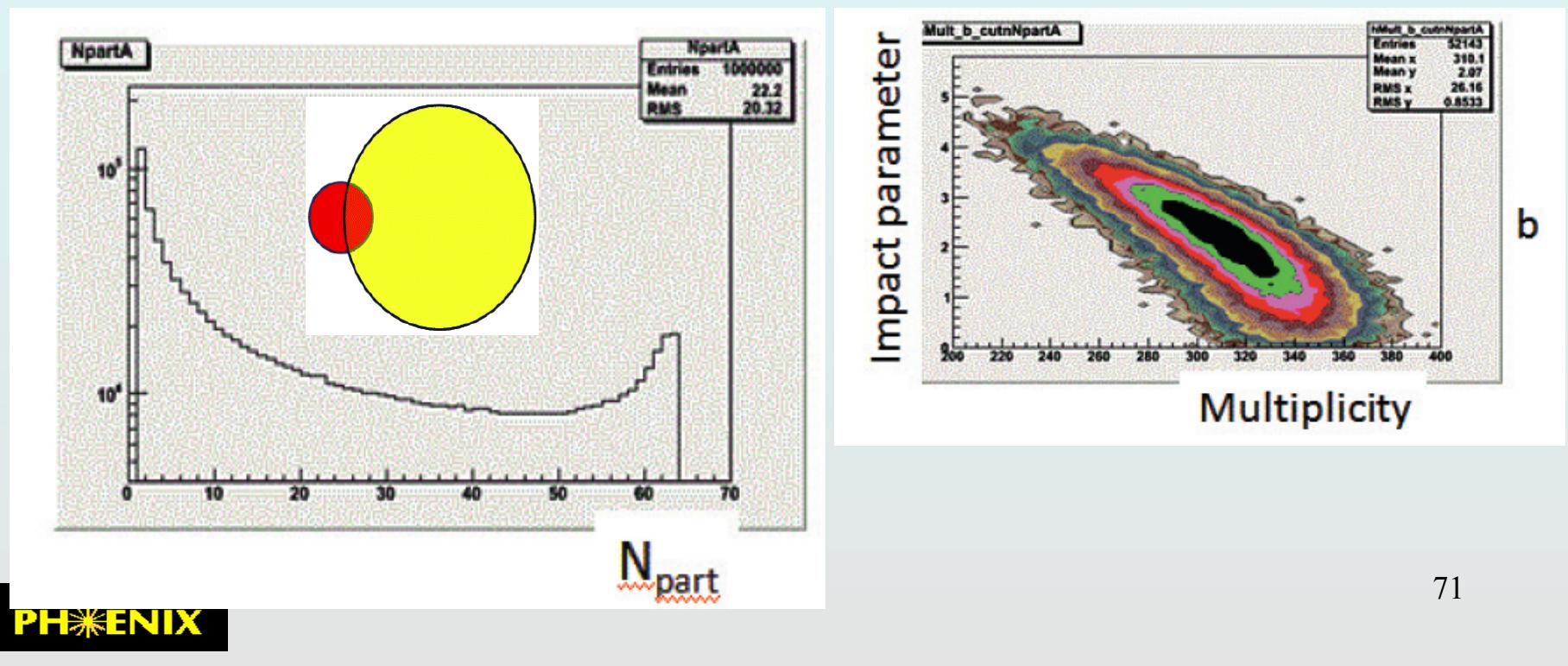
The problem

The solution: 200M evt  
 $\sim 400k$  tip-tip events



# Cu+Au: 2.4 nb<sup>-1</sup> into 10 cm vertex cut

- Cu buried inside Au for most central collisions  
Minimize effects of the surface on hard probes  
select top 3% centrality for this (300M events)
- Eccentricity without left/right symmetry for non-central collisions  
Non-fluctuation source of odd harmonics



# HBD performance: figure of merit $N_0$ and single electron detection efficiency

- ❖ The average number of photo-electrons  $N_{pe}$  in a Cherenkov counter:

$$N_{pe} = N_0 L / \bar{\gamma}_{th}^2$$

with:

- $N_0 = \frac{\alpha}{hc} \int \epsilon(E) dE = 714 \text{ cm}^{-1}$
- $\bar{\gamma}_{th} = 29$
- bandwidth: 6.2 eV (CsI photocathode threshold) - 11.5 eV ( $\text{CF}_4$  cut-off)

| $N_0$ ideal value                  | 714 cm <sup>-1</sup> |
|------------------------------------|----------------------|
| Optical transparency of mesh       | 88.5 %               |
| Optical transparency of photocath. | 81.0 %               |

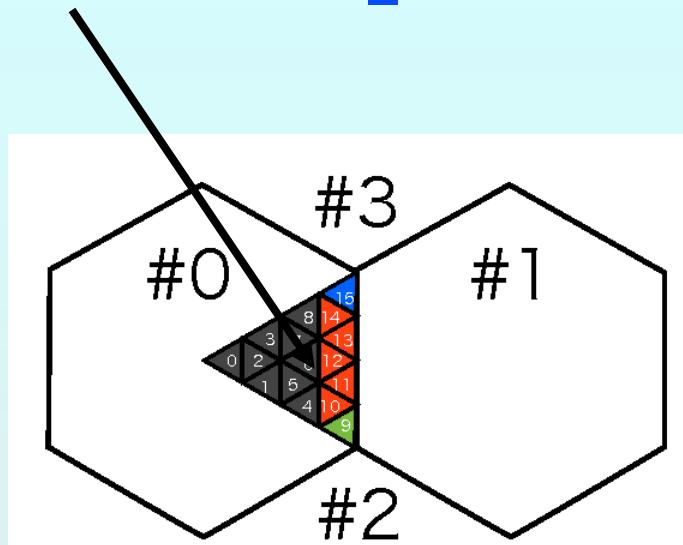
**Quantum efficiency kept constant during the two years of operation!**

**The highest ever measured  $N_0$ !**

|                      |                      |
|----------------------|----------------------|
| $N_{pe}$ measured    | 20                   |
| $N_0$ measured value | 330 cm <sup>-1</sup> |

The high photoelectron yield → excellent single electron detection efficiency:  
→ Single electron efficiency using a sample of open Dalitz decays:  $\epsilon \sim 90\%$   
→ Single electron efficiency derived from the J/Ψ region:  $\epsilon = 90.6 \pm 9.9\%$

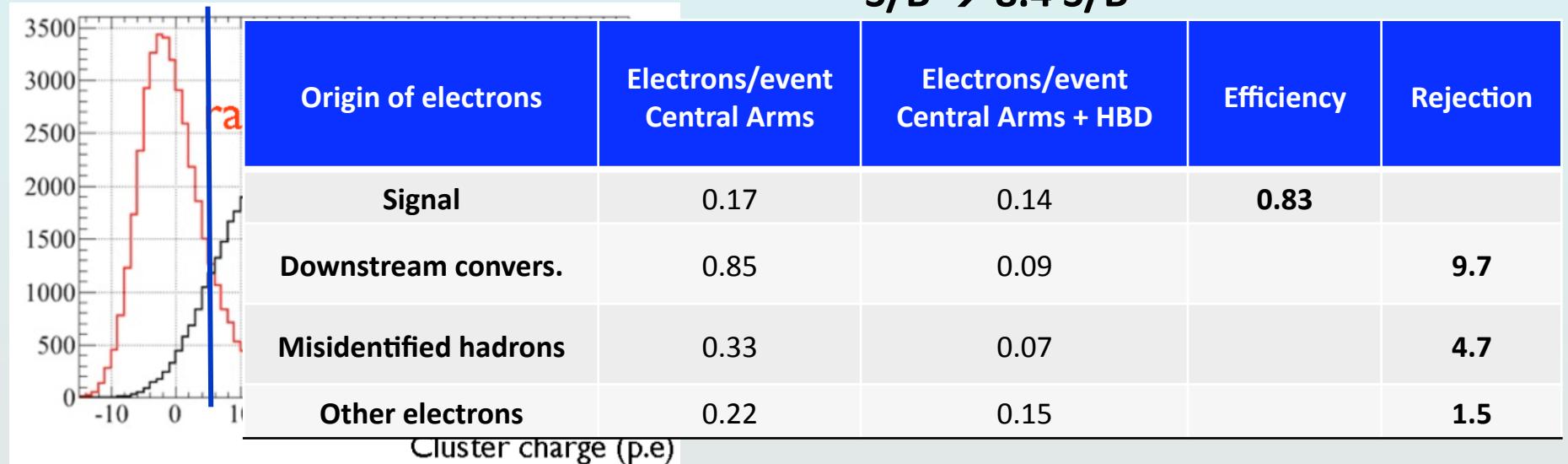
# CF<sub>4</sub>: good N<sub>0</sub> but it also scintillates



Analysis steps (being optimized now):

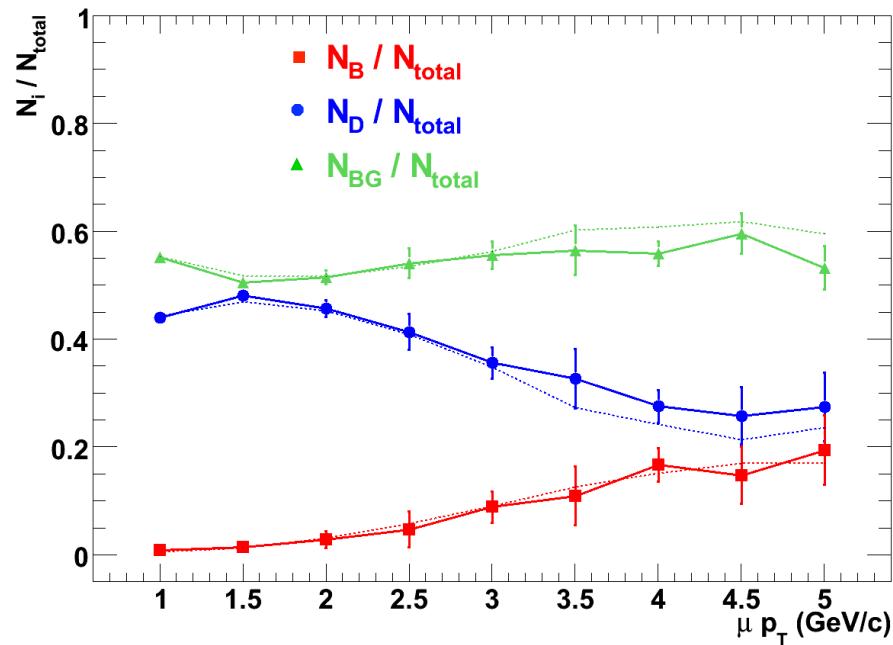
1. Subtract underlying event
2. Reject electrons created downstream of the HBD
3. Reject  $\pi^0$  Dalitz, conversions created upstream

MC study: Matching to HBD only:  
 $S/B \rightarrow 8.4 S/B$

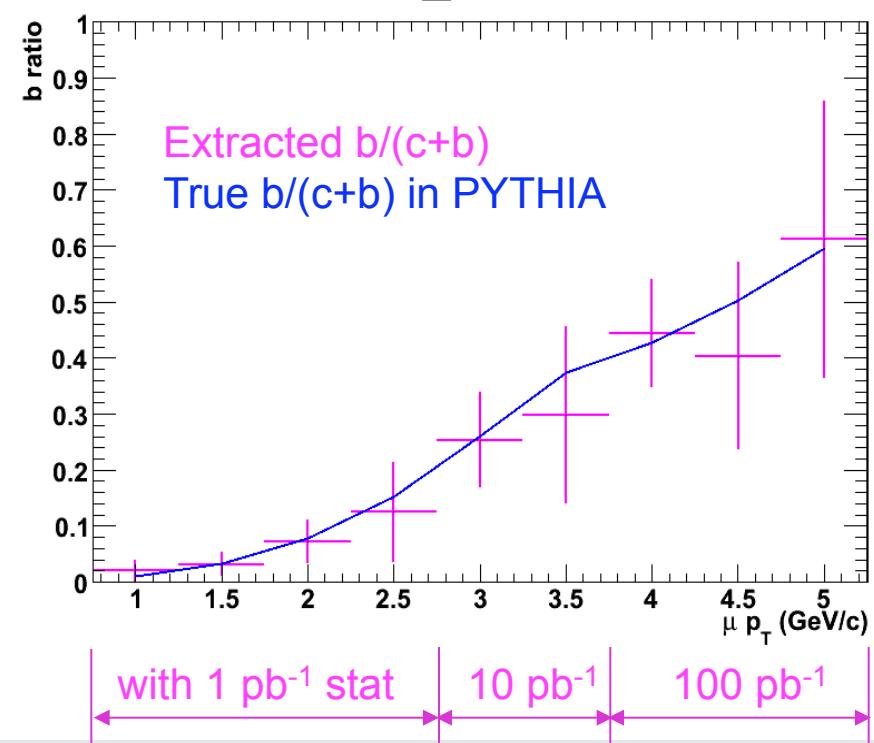


# Beauty & charm separation at different muon $p_T$

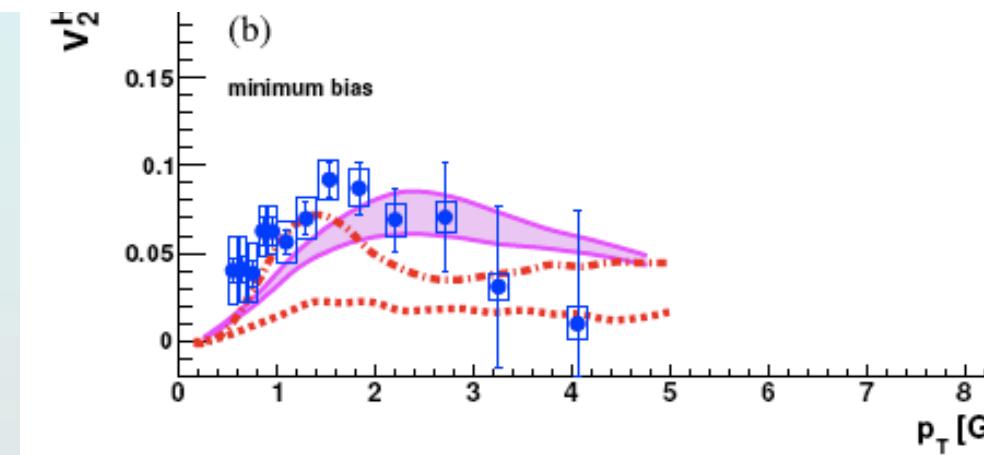
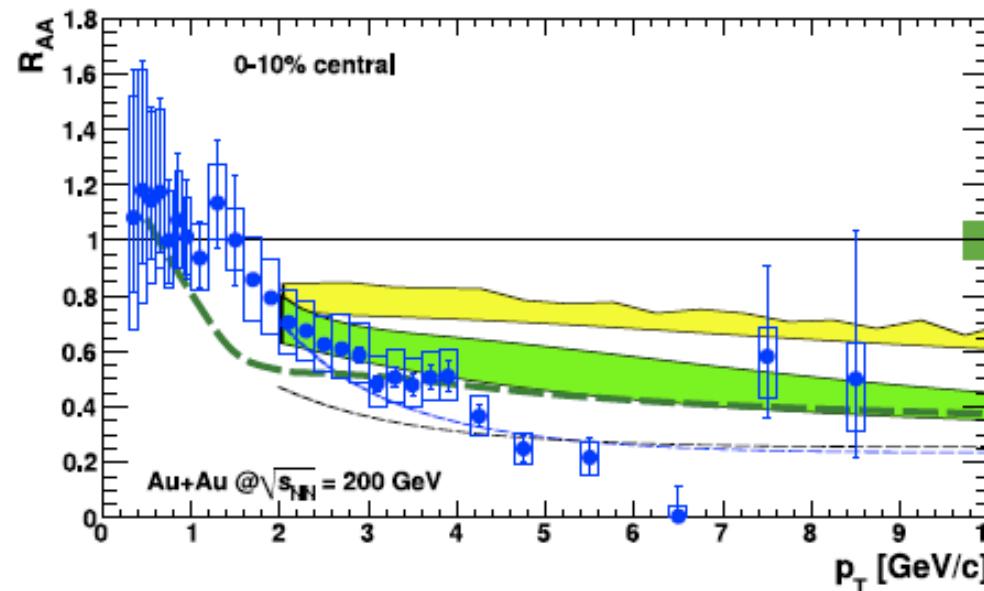
Extracted fraction  $\mu$  from D / B / Bkgnd



$h_{\text{bratio}}$



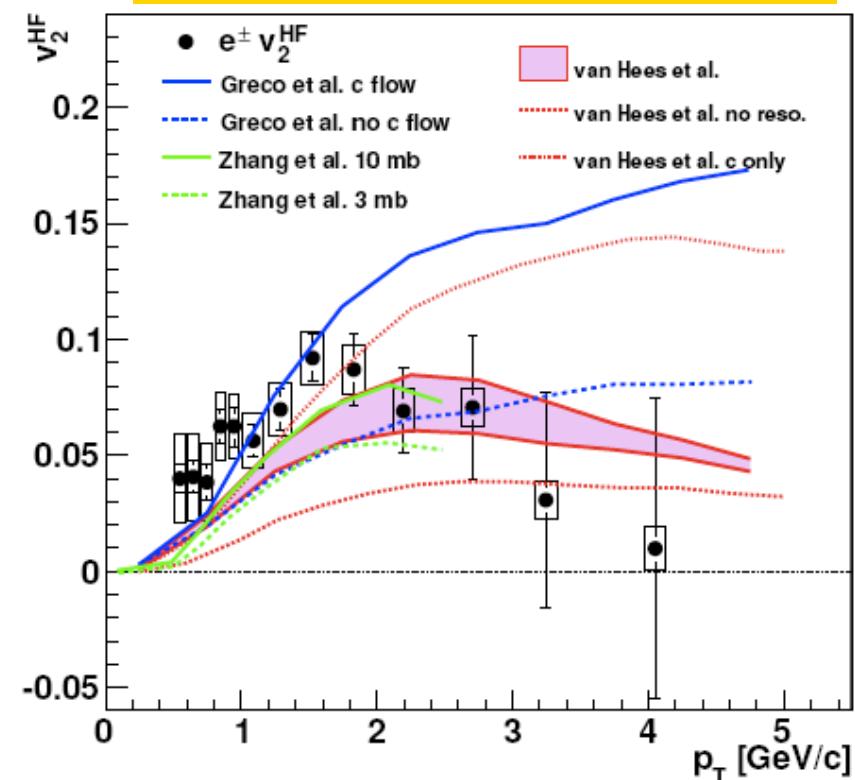
# heavy quark suppression & flow?



PRL.98: 172301, 2007

arXiv: 1005.1627

Collisional energy loss?  
 $v_2$  decrease with  $p_T$ ?  
 role of b quarks?



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14 Countries; 70 Institutions



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August 1998

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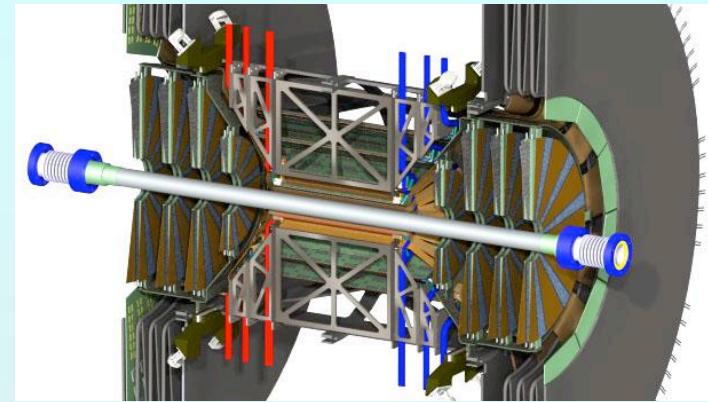
University of Tennessee, Knoxville, TN 37996, U.S.

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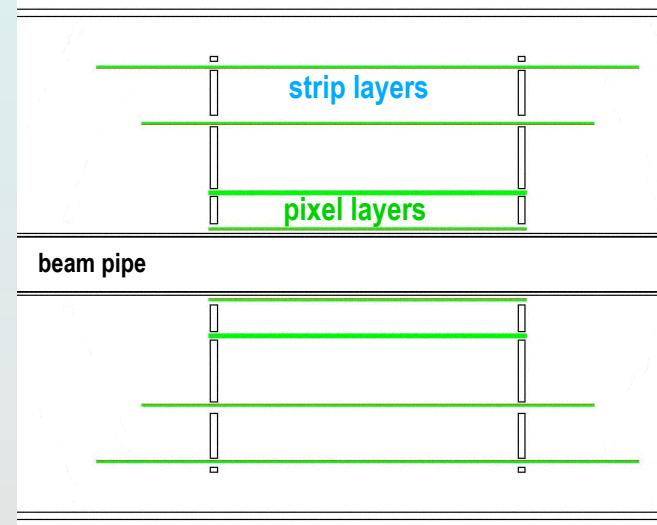
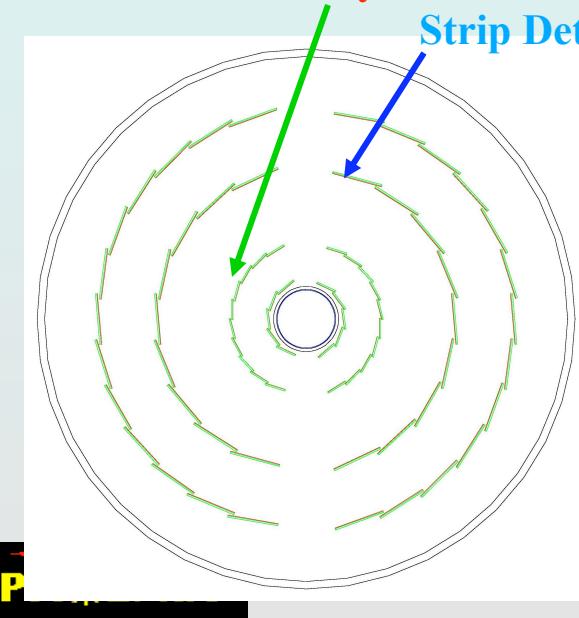
# Barrel VTX Detector

- Specifications:
  - Large acceptance ( $\Delta\phi \sim 2\pi$  and  $|\eta| < 1.2$ )
  - Displaced vertex measurement  $\sigma < 40 \mu\text{m}$
  - Charged particle tracking  $\sigma_p/p \sim 5\%$   $p$  at high pT
  - Detector must work for both HI and pp collisions.

- Technology Choice
  - Hybrid pixel detectors developed at CERN for ALICE
  - Strip detectors, sensors developed at BNL with FNAL's SVX4 readout chip



Hybrid Pixel Detectors (50  $\mu\text{m} \times 425 \mu\text{m}$ ) at R  $\sim 2.5 \& 5 \text{ cm}$   
Strip Detectors (80  $\mu\text{m} \times 3 \text{ cm}$ ) at R  $\sim 10 \& 14 \text{ cm}$



$|\eta| < 1.2$   
 $\phi \sim 2\pi$   
 $z \sim \pm 10 \text{ cm}$

# Forward Silicon Vertex Detector - FVTX

## FVTX Specifications:

- 2 endcaps
- 4 pixelpad layers/endcap
- ~550k channels/endcap
- Electronics a mod of BTeV readout chip
- Fully integrated mech design w/ VTX
- $2\pi$  coverage in azimuth and  $1.2 < |\eta| < 2.4$
- Better than  $100 \mu\text{m}$  displaced vertex resolution

